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Geo. H. Harries.

THE MOTORMAN AND HIS DUTIES

A Handbook of the Theory and Practice of
Electric Railway Car Operation

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Sixth Edition Revised and Enlarged
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CHICAGO
THE WILSON COMPANY
1907

PREFACE.

The purpose of this book is to familiarize the reader with the operation of an electric car. It will be found to explain in simple language, devoid of mathematics and technicalities, many points not generally understood by the average employe who has to do with the operation or care of electric railway rolling stock. Such a knowledge cannot fail to make his services more valuable to his company and more satisfactory to himself, and it will also better fit him for promotion.

This book is intended not only to explain the parts of an electric motor car, but to give some general instruction and advice to those who desire to make the handling of cars their livelihood. It is based on experience gathered during a number of years in the electric railway field, instructing motormen in their duties and work, and on results and observation made while operating roads To explain some electrical effects it has been necessary to adopt a few comparisons, which, though not exactly correct from a scientific standpoint, give the reader a clear picture of what is meant.

The author desires to acknowledge the generous assistance of the manufacturing companies whose apparatus is explained and illustrated in the following pages.

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CHAPTER I.

A GLANCE OVER THE ROAD.

One who will read and study as well as gain by his practical experience will be worth to his employer much more than is the average employe of today. Therefore, he should be able to secure a position more readily. It is evident that the more one knows about his vocation the better compensation he can expect. A man may start "on the platform" and by faithful service and study he may advance to be a car inspector, line inspector and eventually electrician of the road.

Anyone wishing to qualify himself for car service can advance in two ways—by experience in operating a car and by studying the theory of the electrical equipment. For rapid advancement the practical work should be accompanied by electrical reading.

The reader who desires to become proficient and know more than just simply enough to run his car over the road should be of a practical and mechanical turn of mind. He should know something about the use of tools and machinery. To become familiar with the electric car equipment the best plan is to work at first in the barns and repair shops. One will there

learn the practical side. He will have to mount motors on trucks or repair defective pieces of machinery, and by frequently handling them he will soon familiarize himself with their names and uses. However, not everyone can have such preparation for a position, and for this reasen we will do the next best thing, namely, take an imaginary trip first over the road and then

Figure 1—Interurban Right of Way.

through the car shops, mentioning briefly the various parts of the whole system and the devices that are necessary to operate it. Such of these devices as come under the control and care of the motorman and conductor will be described in detail later on and the principles by which they operate will be explained.

Essential Parts of an Electric Railway.—To begin with, every road has its right of way; the cars of the city roads operate over tracks laid in streets, while those of interurban roads (Figure 1) run over tracks built on a private right of way located across the country without regard to public roads. By cutting down the hills and filling in the low places it is possible to build a track in the country over which the cars can operate at much higher speeds than in cities where the grades and curves of the rails must fit those in the streets. It is also much more difficult to operate cars through the crowded streets of a city or town than it is on a fenced right of way.

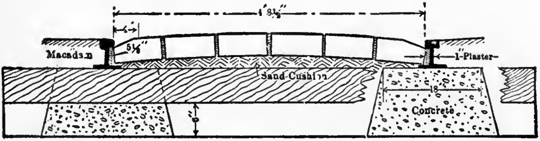
Nearly everyone is familiar with the track and roadway of a steam railroad, and, as the better interurban electric railways are built with tracks as near as possible like steam roads, this subject need not be thoroughly discussed here. The tracks of city roads, however, are very different from those of steam railroads. The latest kinds of track for street railways have a very substantial foundation of concrete on which the track rails rest, as shown in Figure 2. In some cities ties are used and in others the rails are sunk into stringers of concrete and held to the standard gauge of 4 feet 8½ inches by iron tie-rods.

The electric current for use in operating the cars as they move along the track is generated in the power house and carried to the cars through a trolley wire or third rail, which, in fact, are no different as regards the movement of the car, except that the trolley wire is hung above the middle of the track and is usually of copper, while the third rail is supported alongside of the track.

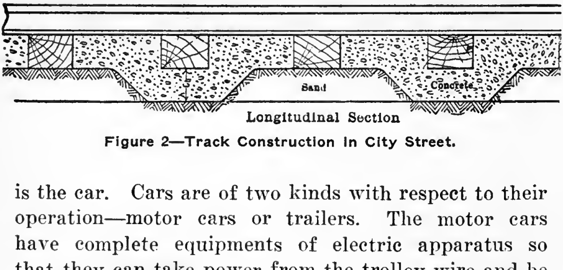
It should be understood that the electric current

in the wires may be serving to transmit hundreds of horsepower of energy and yet the wire look "dead." It is necessary to be cautious about coming in contact with electric wires and nothing should be touched that may be connected in any way with the circuit; otherwise, a severe shock will be received.

Electric Cars.—Probably the most important part of an electric railway from the motorman's standpoint



Transverse Section



Longitudinal Section

Figure 2—Track Construction in City Street.

is the car. Cars are of two kinds with respect to their operation—motor cars or trailers. The motor cars have complete equipments of electric apparatus so that they can take power from the trolley wire and be propelled along the track under the control of a motorman on the front platform. The trailer cars do not have this electrical equipment, but are hauled by motor cars, thus requiring the services of a conductor only to collect the fares.

So-called open cars consist of a floor structure usually with cross seats, a roof and a foot-board or step all along the side of the car. To protect the passengers in rainy weather open cars are provided with curtains which may be drawn down between the posts which support the roof. Closed cars (Figure 3) have sides up to about the tops of the seats and windows fitted in between the roof posts and this siding. Platforms are usually provided for both ends of closed

Figure 3—Single-Truck City Car.

cars and passengers must step onto these platforms first before getting inside the car.

Both open and closed cars are used for city service, but for interurban service the closed car body only is used (Figure 4).

A motor car is composed of the following essential parts:

1. A car body for carrying the passengers.
2. Trucks and wheels for supporting the motors and the car body.
3. Motors for propelling the car.

4. A device for collecting the current from the wire or third rail.

5. Controllers for feeding and regulating the current used by the motors.

6. Brakes for stopping the car.

7. Devices for protecting the electrical apparatus.

Figures 5, 6, 7 show different constructions of car trucks, but these are only a few of the types which are in general use. Figure 5 shows a type of running gear used on short cars of from 25 to 30 feet in length. Strictly speaking this is not a truck, but two pairs of wheels, each pair and its axle being connected with the car through springs. Figures 6 and 7 show bogie trucks which are

Figure 4—High-Speed Interurban Car.

used with long cars, two such trucks being used under each car. The essential parts of car trucks are two sets of wheels mounted on axles which are held in position by bearings. The bearings are fixed to side frames

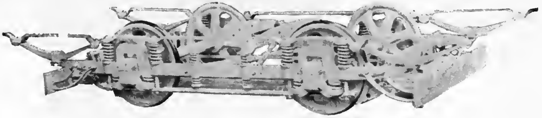


Figure 5—Running Gear for Single-Truck Car.

which give the truck its rigidity. Springs are placed between the bearings and the parts.

The brake rigging is also a very important part, on which the car body rests in order to prevent too severe jarring of the car body. In the case of the

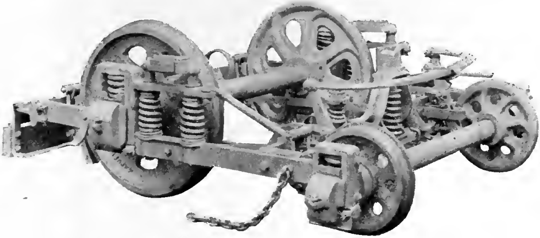


Figure 6—Maximum Traction Truck for City Car.

"single truck" the lower sills of the car are bolted directly to the side frames of the truck, but where double trucks are used a piece known as the truck bolster extends between the two side frames and is pivoted at its center to the car-body bolster.

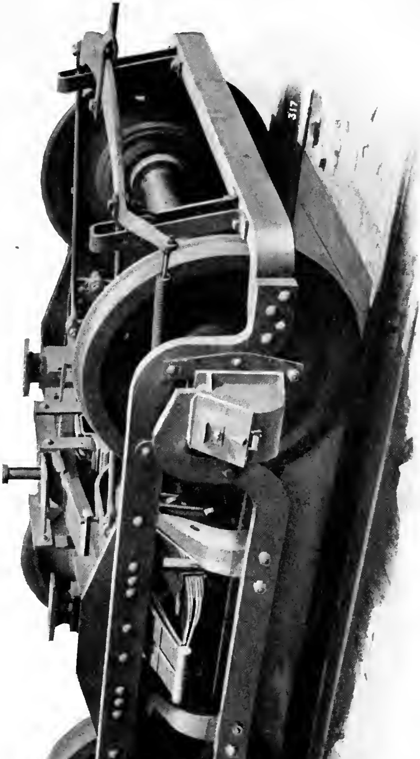


Figure 7—Truck for High-Speed Cars.

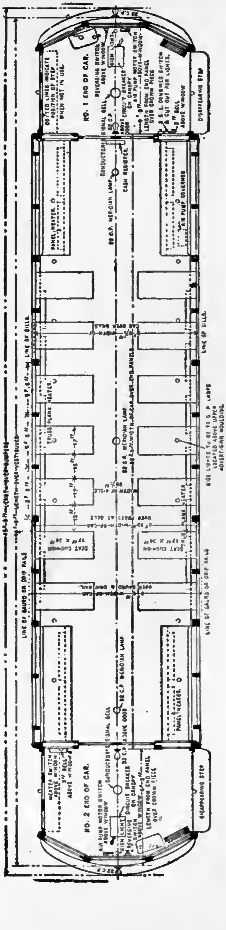


Figure 8—Floor Plan Chicago City Railway Car.

The brake rigging, which will be described in detail in a later chapter, is also a very important part of the equipment of the truck, and on most modern electric cars both hand and power brakes are used. The hand-brakes are operated by manual force, but the air-brakes utilize the power from the trolley wire, as will be explained in a later chapter.

Figure 3 shows a car mounted upon a single truck, this being a type of equipment suitable for operation on city lines. Figure 4 shows a double-truck car built for use on a western high-speed interurban railway. Figure 8 is a floor plan of a large city car arranged in such a way that loading and unloading is very rapid. The location of the different parts and fittings is shown and an idea of the relative dimensions given.

CHAPTER II.

THE PRINCIPLE OF THE ELECTRIC MOTOR.

Many persons have the idea that a dynamo or an electric motor is so complicated a device that it takes years of study to understand it. Nothing is farther from the truth. The fact is that it is built on one of the simplest principles, and if this principle is well understood it will be easy to understand any machine, because in analyzing we always go back to the simple principle and leave out the many complicated additions which may be attached to a machine for one reason or another.

Principle of the Magnet.—A dynamo or motor frame is a powerful steel magnet, and differs in principle but slightly from the common horseshoe magnet. Figure 9 represents a magnet which one can buy in any hardware store. To understand the action of a dynamo or motor, it becomes necessary to understand

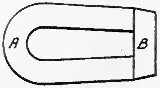


Figure 9.

this little magnet. It is a piece of flat steel bent into the form of a horseshoe, which is hardened and afterward magnetized. It has been found that steel, when hardened, will retain magnetism for a long time, that is, for months and years; provided, that it constantly

has some work to do. For this reason the keeper B is always found with the magnet. The keeper or armature B is a simple piece of soft iron which, when brought near to the end of the magnet poles or the horseshoe, is attracted and held by the magnet. If we attempt to remove this piece of iron B from magnet A we find that it requires some force — that it takes energy to pull off the iron piece from the magnet. We therefore are confronted by the fact that this bent piece of steel has energy stored in it, and that this energy is capable of doing work. The magnet, which at first had to be charged, takes up energy which is stored in it, and which afterward it can return to do

Figure 10.

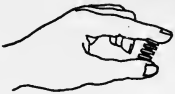


Figure 11.

useful work. It is similar to a spiral spring. We have to spend energy to compress it (Figure 10), but the moment we reduce the pressure we feel that the spring tries to utilize the stored energy and force our fingers apart (Figure 11).

If we remove the armature from the horseshoe magnet, the energy acts from one end of the magnet to the other through the air. The energy or flow of energy is not visible to the eye, but the results of this force are made visible by the action of iron filings when brought near to a magnet. With the aid of iron filings it is found that this force is very intense near and between the ends of poles, and spread in curves the farther it goes out into the space surrounding the

magnet poles. Figure 12 gives a clear view of some of these lines. The spots which are marked N, S, are the places where the paper would touch the ends or poles of the magnet, if it were held beneath the sheet of paper presenting the figure.

The iron filings which are thrown on top of the sheet arrange themselves in lines as seen. Between the poles these lines appear straight, and become more and more curved the longer the path becomes from one pole to the other. It must, however, be borne in mind that the sheet is but a single plane through the sphere or globe surrounding the magnet, and that the power of activity goes in all directions surrounding the poles, as the branches and leaves surround the trunk of a tree. These same curves of activity can be seen to go in all directions in space by taking a small compass needle and passing it from one pole to the other. During its travel the needle will change its position with relation to the two poles, and will always take such a position that its two ends lie in line with the particular curve which unites it with the two poles (Figure 13). It is owing to this custom of representing this force by the curved lines that it became usual to speak of "magnetic lines of force," which, however, should not be considered as actual lines, nor that they simply connect the two poles, but as a force which threads through the whole length of the magnet, as shown in Figure 14. This energy is vested not only in the extremities of poles, but is the sum of the forces of all the particles of steel constituting the magnet.

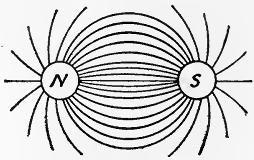


Figure 12.

The energy is in the magnet, but its manifestations become apparent most strongly at the points where it passes from the magnetic medium to a non-magnetic one. Air is non-magnetic, while iron and steel are strongly magnetic substances. Owing to the great preference that the magnetism has for iron, it selects the path indicated in Figure 14 rather than to go straight from the pole N to the S pole through the air. In passing through the iron the lines of magnetic force cause the armature or keeper also to become a magnet. The poles are marked N and S as abbreviations for "North" and "South," because they correspond to the poles or ends of the magnetic needle of a compass.

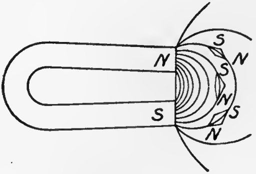


Figure 13.

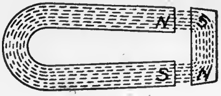


Figure 14.

The keeper becomes a magnet under the influence of the horseshoe magnet.

If we substitute for the keeper a permanent magnet, viz., a piece of steel in which the poles are fixed, we find that if the two magnets are faced N to S and S to N, as in this figure, they will attract each other. If placed so that the two N poles are together and the two S poles are together, no attraction will take place, but, on the contrary, they will repel each other; and from this fact comes the rule "like poles N, N, or S, S, repel each other: unlike poles attract each other."

Electro-Magnets.—A great step in advance was

made when the following fact was discovered: It was found that if a wire carrying an electric current and a magnetic needle, delicately suspended, were brought close to each other, the needle was deflected to one side. If the current flowed in a wire above the needle in the direction from south to north, that is, if the wire itself was held in a direction due north and south above the needle, and the current flowed north through the wire, then the north-seeking end of the needle was deflected to the west. If the wire was held above the needle, but turned round so that the current flowed

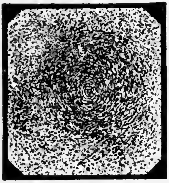


Figure 15.

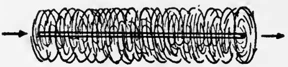


Figure 16.

from north to south, then the north-seeking point of the needle was deflected to the east. Lastly, if the wire was held below the needle, the direction of the deflection was reversed. It was clear, then, what long had been suspected, that there was some connection between magnetism and electricity.

This experiment also showed that the electric current could act through space, and acts on the magnetic needle just as the horseshoe magnet did. If that is the case, then it must disturb the space surrounding it while a current is flowing; it must establish a sphere around itself of the nature of a magnet, a sphere that has magnetic properties. Investigating the space

around the wire with iron filings, we find a grouping of the little iron particles (Figures 15 and 16), and that the wire carrying a current attracts iron filings. Figure 16 shows a picture of the force around the wire, while Figure 15 shows an end view of Figure 16.

Figure 17 represents a magnetic needle surrounded by a coil of wire carrying a current. It appears that we have here the principle of an electric motor with this one difference, that owing to the arrangement of parts the movement is not rotary. Motion is imparted, but not continuous motion, in one direction. It is

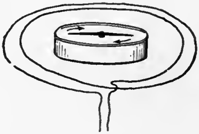


Figure 17.

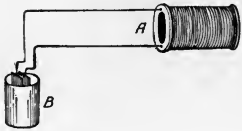


Figure 18.

found further that if we take a spool of wire (Figure 18) without any iron near it and send an electric current through it, as, for instance, from a battery B, through the coil A, it behaves just as a magnet does; viz., that it exhibits a north pole at one extremity and a south pole at the other, and that it attracts one end of the magnetic needle at one end and the other at the opposite end—just what we know will take place if we have an ordinary straight magnet or bar magnet instead of the spool with the current flowing through it.

Lastly, one more phenomenon must be mentioned, which will complete our picture. If we take a spool of wire A (Figure 19) and connect it to another coil B

several feet away, which is close to a magnetic needle C, and we move a magnet D toward the first coil A, then the needle momentarily is deflected. The needle C is far enough away not to be under the directing influence of the magnet D. What takes place is this: The sphere surrounding the magnet pole in its approach affects the coil A, and this disturbance in space is the cause of the flow of an electric current in coil A, which, passing through the coil B, disturbs the air surrounding it and changes it into a magnet, which in

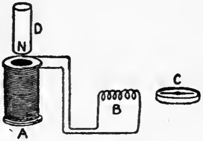


Figure 19.

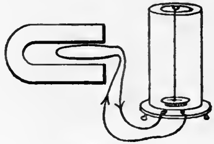


Figure 20.

turn acts on the compass needle. Here we have one of the earliest transmissions of power to a distance.

Principle of the Dynamo.—Returning now to our simple magnet (Figure 20), it will be clear and in accordance with facts that if a loop of wire, placed between the poles of a horseshoe magnet and connected to a delicate instrument for measuring electric currents, is turned between the poles of this magnet, such turning produces a temporary current which affects and deflects the needle of the instrument. An electric current is generated which flows from the loop to the instrument and back again, with the effect of deflecting the needle of the instrument. What has been found is that taking a magnet and turning a coil of wire in its sphere of activity, or (as it is called technically) in its

magnetic field, an electric current is created or generated in this coil. The reader will now see that if this simple magnet, with a loop or a coil placed between its poles, is conveniently arranged on a shaft so as to turn it continually in the same direction (Figure 21), a current will be produced that will last for some time instead of being simply an impulse; this constitutes a dynamo in its simplest form. Owing to its primitive mechanical arrangement, and also owing to the weakness of the permanent magnet, such an arrangement, of course, gives but very weak currents and is not a com-

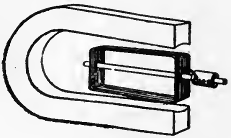


Figure 21.

Figure 22.

mercial device, but this fundamental idea can be recognized in any and all of our modern machines.

The Dynamo.—Now let us start once more with our permanent magnet and go through the evolution until we reach the dynamo of today. Figure 9 shows the permanent horseshoe magnet with its keeper in place. Figure 22 shows the keeper or armature, as we will call it hereafter, some distance from the poles, with the field of activity in the space between the poles and the armature. The armature, under the influence of the magnet, becomes also a magnet and must exhibit poles, which are indicated by the letters N S, N S, in such a way that a south pole of the armature will stand before a north pole of the magnet. Under these conditions the force exerted causes mutual at-

traction between the magnet and its armature, resulting in a motion of the smaller piece, which moves toward the magnet, where all motion stops when it rests against the poles. If we now wind a coil around the armature, we will obtain a temporary current which lasts as long as the armature is approaching the poles (Figure 23), but as soon as the armature comes to rest the current ceases. In a dynamo it is desired to produce currents continually, and therefore it is necessary to modify the form and relationship of the armature to the magnet. This is shown in Figure 24. In this case the armature is mounted on a spindle, a

Figure 23.

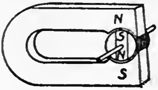


Figure 24.

cylindrical piece of iron, which, magnetically considered, is a bar, as in Figure 22. Figure 25 shows a magnet like Figure 24 with the wires wound around the cylindrical armature core. The wires and the shaft are shown in section. The wire, which is to be rotated in the space of magnetic activity, is placed as near the poles as possible, as shown in section in Figure 25. This figure is obtained by placing the magnet in the plane of the leaf or book (Figure 26). The armature and wires lie at right angles, penetrating through all the leaves. If the armature in Figure 26 be cut off, the end that projects on top is shown in Figure 25.

The Commutator.—To use the currents generated and bring them to devices, such as lamps or motors, we have to make some provision for collecting the elec-

tric current from the rotating armature to stationary points. This is done by connecting the ends of the rotating coils to metallic contact pieces or rings, called a commutator, which will be explained later.

Field Magnets.—To produce strong currents strong magnets are needed. It was found that permanent steel magnets were weakened when an armature with winding was made to generate heavy electric currents. It also was found that soft iron, when wound with coils through which a current was sent, became a far more powerful magnet than could be obtained in any

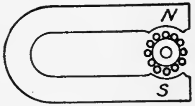


Figure 25.

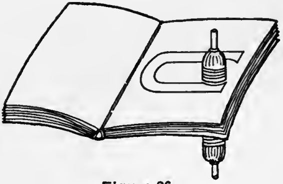


Figure 26.

other way. Therefore it became the practice to use wrought iron, cast iron or soft steel magnets for dynamos, and to magnetize them by a winding through which an electric current is sent as long as the machine is working. Figure 27 shows our simple magnet provided with energizing coils, which, to distinguish them from the windings on the armature, are called the field magnet windings, or, in short, the field windings, because they belong to that magnet which establishes the field in which the other part or armature is to rotate. Between the magnet poles is the armature with a winding and contact device or commutator.

If we now compare the complete dynamo with the

original magnet, we find that the only difference between them is that the dynamo is made more powerful than the magnet by the application of the coils, and the differences in the armatures are that the motion is changed from a lateral to a rotary one; further, that the armature is provided with a winding and a device for conveniently taking off the current generated by the rotating of the armature winding in the sphere of energy of the magnet. It therefore is clearly seen that there is no frictional contact required between the armature and the field magnet, an erroneous view so frequently expressed by people not conversant with the subject.

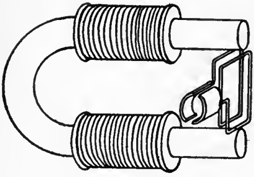


Figure 27.

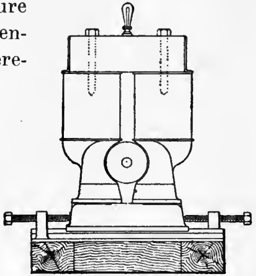


Figure 28.

We are now prepared to look critically at any kind of a dynamo, from the simplest and weakest to the largest machines built today, without confusion and without the idea of great complication as regards the nature of its operation, for now the single magnet with the single loop between the poles will be ever present before the mental eye.

Figure 28 shows the outline of an Edison dynamo, one of the older types. The horseshoe magnet with its windings will readily be recognized in this machine. It

is built with its poles downward and its armature between the poles, which are extended so as to surround the armature. Figure 29 shows a front and side view

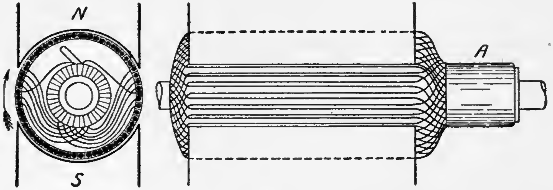


Figure 29.

of the armature, the iron core being completely covered by the wire. On the right side may be seen the contact terminals, called the commutator, which is marked A. Figure 30 is a skeleton of a multipolar (many poles) field magnet, which shows a magnet with four poles and consists of four horseshoe magnets, one of which is shown shaded. The armature is shown located between the poles. This elementary description, explaining the nature of the generation of an electric current, shows clearly how simple is the principle underlying an electric machine. It is a magnet at rest combined with a rotating piece of iron wrapped with wire, that constitutes a dynamo; and furthermore, a machine that is used as a

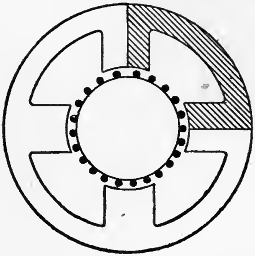


Figure 30.

dynamo may also be used as a motor. The name dynamo or motor changes with the service to be rendered. If the machine shown in Figure 28 be driven by a steam engine, and is supplying electric current, it is a dynamo; if, however, an electric current is applied to it, and it does mechanical work, it is a motor. These differences should be clear in the mind of the reader. If there are parts he does not understand clearly, he should discuss the subject with such persons of his acquaintance as are competent to explain the matter to him.

CHAPTER III.

GENERATING AND DISTRIBUTING POWER.

Now that we have obtained a general idea of the fundamental principles of the electric dynamo and motor we can next more readily understand the power

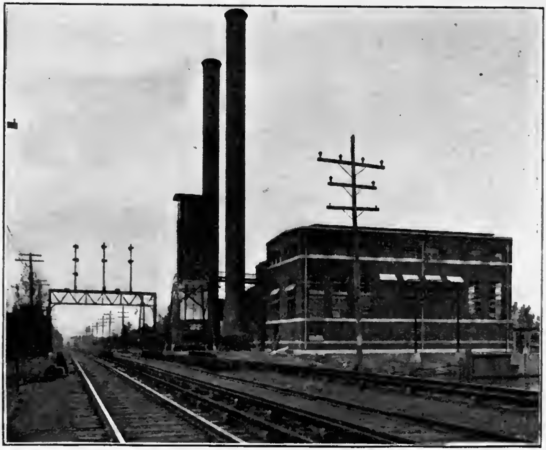


Figure 31—A Large Power Station.

system of an electric railroad. We shall make a mental inspection of the power generating and distributing apparatus, beginning with the coal pile in the boiler

room and ending with the car in charge of the **motorman.** In a subsequent chapter it will be shown how important it is that a motorman should recognize the value of power and therefore learn to operate his car in the most economical way.

The Power Station.—To begin with, a power station usually is a fireproof building **in which** are housed boil-

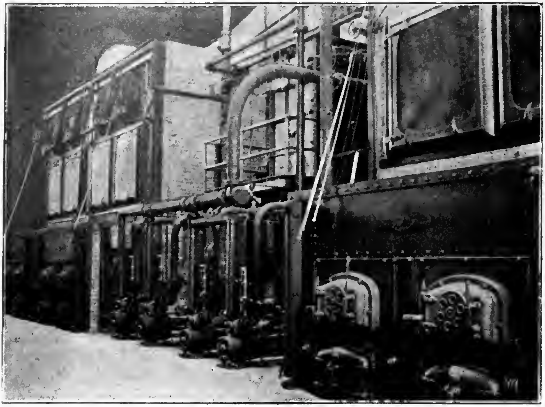


Figure 32—Boilers and Pumps.

ers, engines, dynamos and electrical switching apparatus. Here the current is generated and, by means of wires on poles along the track, it is distributed for use in propelling the cars. The machinery in some power stations is operated by water wheels, but the larger number of power plants are run by steam engines.

Boilers.—To make steam for running the engines which drive the dynamos, a battery of boilers is necessary. These boilers comprise two types, known as "water tube" and "fire tube." The fire-tube boilers are seldom used except for very small plants. They are called fire-tube boilers because the burning gases from the coal on the grates pass through a number of parallel iron tubes around which is the water. In the water-tube boilers (Figure 33), the relative spaces oc-

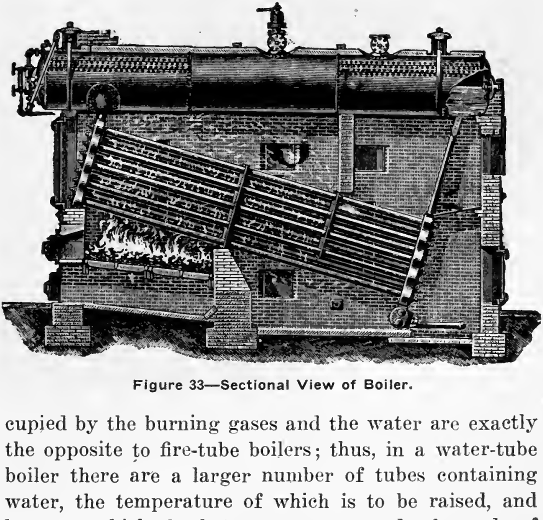


Figure 33—Sectional View of Boiler.

cupied by the burning gases and the water are exactly the opposite to fire-tube boilers; thus, in a water-tube boiler there are a larger number of tubes containing water, the temperature of which is to be raised, and between which the hot gases are passed; the ends of these tubes filled with water connect with cylindrical "drums" in such a way that when the water in some of the tubes that are over the hottest part of the fire becomes heated, it can rise into one of the drums and

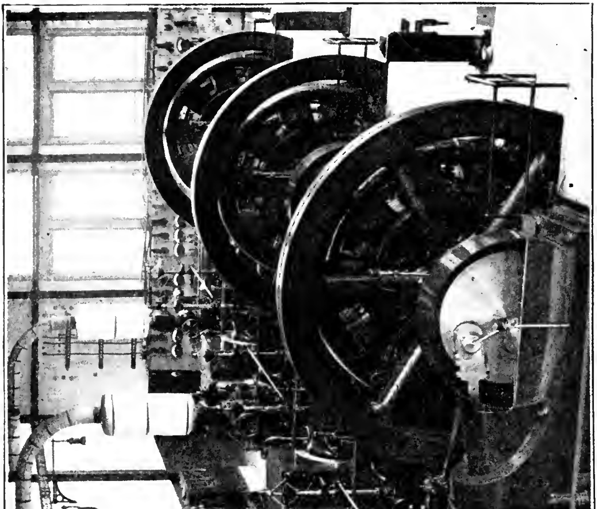


Figure 34—Engine-Driven Generators.

the cooler water in the drum pass down through tubes in the hotter part of the fire, and thus a circulation take place.

The water-tube type of boiler is more generally used in large power plants because of its economy and safety.

The fuel used for making steam in boilers usually is coal, although some power plants find it economical to burn crude oil. The grates on which the coal is burned are built directly under the front of the tubes in the boiler, and coal is fed onto them either by hand or by mechanical stokers. The gases from the burning coal make several passes between the rows of tubes and then leave the brick setting which encloses the firebox and boiler and connect with the stack.

Steam Engines.—The steam is taken out of each one of the boilers and fed into a large pipe called a main header. From this pipe branches lead to the engine's cylinders. Practically everyone is familiar with the general appearance and mechanical operation of a steam engine having as its essential parts a cylinder within which a closely fitting piston is moved back and forth by steam pressure. This piston transmits the power thus generated through a piston rod and a connecting rod to a crank pin on the engine shaft. Thus the back-and-forth motion of the steam-driven piston is transformed into the rotary motion of the engine shaft revolving in its bearings (Figure 34).

The electric generator whose elementary principles we have already discussed is usually mounted on the same foundation with the engines, so that the revolving part of the generator, called the armature, can be driven directly by the shaft of the steam engine.

A heavy flywheel of large diameter is also driven on the same shaft. This flywheel is for the purpose of carrying the connecting rod over the dead-center and

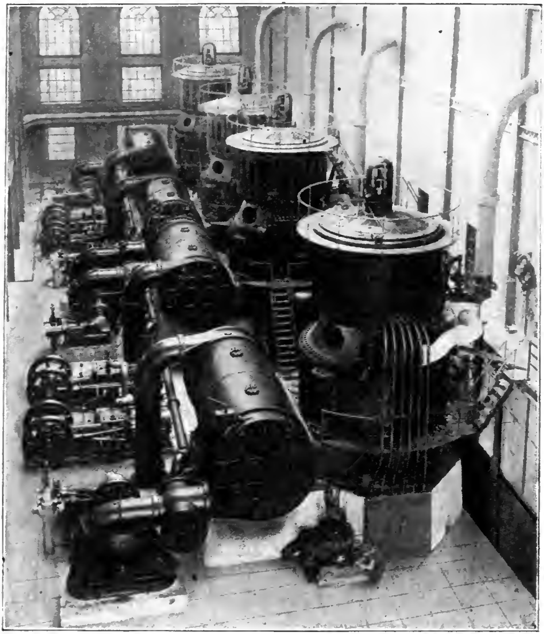


Figure 35—Turbine Units and Condensers.

making the engine and dynamo run at a uniform speed.

Steam Turbines.—The steam engine and its dynamo, as described, occupy a large floor space and therefore require a comparatively large and expensive

building to cover them. There recently has been adopted a type of steam-driven dynamo which occupies much less floor space and is thought to be better suited for electric railway power plants. This machine is known as a steam turbine unit, several of which are shown in Figure 35. It comprises a main shaft on which are mounted a large number of blades inclosed in a steel casing and having a general arrangement very similar to a turbine waterwheel. The principle

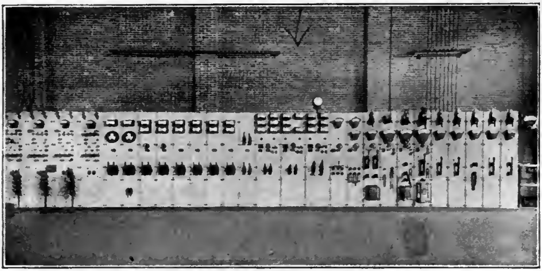


Figure 36—Power Station Switchboard.

on which the turbine operates is simple, the steam in it corresponding to the water in a waterwheel. A dynamo is mounted on the same framework with the turbine, and the armature is built on the same shaft that supports the blades in the turbine. Steam turbines are known as horizontal or vertical, depending on whether the main shaft lies in a horizontal plane or stands vertically on its end.

We have now seen how the coal is burned under the boilers, which generate steam and drive, by means of engines or turbines, the dynamos which develop the electric current that is to be used in propelling our

cars. If there are a number of such generating sets in the power station the current from each dynamo is brought by means of cables to a switchboard (Figure 36) where there are electrical meters for measuring the quantity and quality of the current, and where there are also switches for combining the current generated in each dynamo, so that the total output of the plant may be fed out of the building and along a transmission line to supply the cars.

Units for Measuring Electricity.—To transmit electricity from one place to another a certain amount of energy has to be spent in the transmission which is thereafter not available for useful work. This loss of energy is due to the resistance of the conductor which carries the current, and will be readily understood by its similarity to water flowing through a pipe. If we transmit a volume of water to a distance through a pipe under a certain pressure, the pressure of the water at the further end of the pipe will be considerably less than the pressure at the point where the water enters the pipe. This loss of pressure is due to the friction of the water against the walls of the pipe, and it will be readily seen is greater the greater the length of the pipe, and will be less for a given volume of water as the size of the pipe is larger. And the same way with an electric current: the longer the conducting wire the greater will be the resistance, while by increasing the diameter of the wire the resistance will be reduced. The smaller the amount of loss in the transmitting lines the more economical is the working of the system.

We have spoken of the volume, pressure and resistance of water in a pipe as being analagous to volume, pressure and resistance of current flowing through a conductor. The electrical unit of quantity

corresponding to the volume of water is called the ampere. The electrical unit of pressure is called the volt, and the unit of electrical resistance is the ohm. According to Ohm's law, the current in amperes equals the pressure in volts divided by the resistance in ohms. This law is generally expressed by the equation:

$$C = E \div R$$

in which $C =$ current in amperes
$E =$ electromotive force in volts
$R =$ resistance in ohms.

Methods of Distribution.—In general there are three methods of supplying current to the cars. These are here stated and will be described in detail later on:

1. The simplest plan is to feed all the current into the trolley wire and an auxiliary wire or feeder cable supported on the poles which hold up the trolley wire.

2. The "alternating current" system has practically the same general arrangement as System No. 1, but differs in that it uses the so-called alternating current. This current is generated in the same way as that which we already have discussed, except that there is a difference in the method of making connections between the armature coils and the brushes. We have learned that on the end of the commutator shaft there are placed a number of copper bars to connect with stationary brushes which, by the nature of the method of connections and the rotating of the armature, unite the many small currents passing in different directions through the armature into a large current passing to the outside wires in only one direction. With the alternating current the method of connection at the commutator end of the armature is even

simpler. In place of the many bars there are only two, bent in the form of rings, over which the brushes slip; thus the currents passing in opposite directions through the various armature coils are not fed to the line as current all moving in one direction, but are sent out in opposite directions as the different coils in the armature pass by the north and south poles of the generator. The fact that such current does not flow steadily through a circuit in one direction, but flows first one way and then the other in this circuit, brings about the name "alternating" by which this current is known.

3. The method for economically feeding long lines comprises the use of what are known as alternating-current generators, the current from which can be raised in pressure and fed at a small loss over a long distance, say 50 to 100 miles, and then reduced in pressure; and by means of a combination of an alternating-current motor and a direct-current generator, the principle of which we already have considered, it may again be converted into suitable current for use in the cars and motors which we have mentioned.

The Direct-Current System.—The electrical transmission from a railway power station, according to System No. 1, is shown in diagram in Figure 37. To the left will be noticed the dynamo, which is connected by means of a commutator brush to the trolley wire (all switches, circuit-breakers, safety devices, etc., at the station and on the car have been omitted for the sake of clearness and simplicity). Each electric car is indicated by one motor, wheel, trolley and controller. By following the arrows it will be observed that the electric current starts from the dynamo, goes to the trolley wire, from there to the trolley wheels and to the con-

trollers; from the controllers to the motors, the windings of which are indicated by a few turns, and from there to the iron body of the motor, to the car wheel and to the rail. Through the rails and return feeders it flows back to the station, where the second brush of the dynamo is connected to the rail. This completes a circuit, through the dynamo, out over the trolley wire, down through the motor and back through the

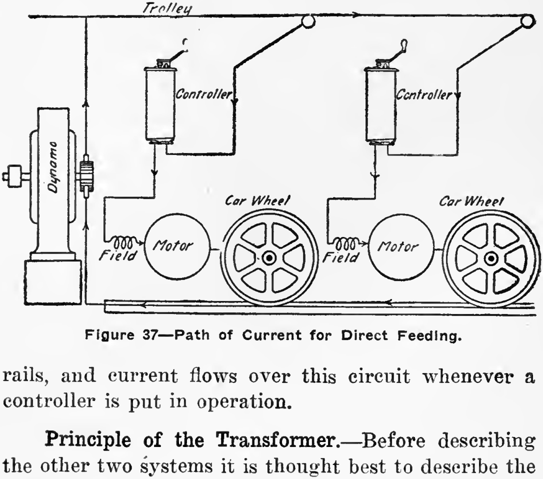


Figure 37—Path of Current for Direct Feeding.

rails, and current flows over this circuit whenever a controller is put in operation.

Principle of the Transformer.—Before describing the other two systems it is thought best to describe the transformer, which is an important piece of apparatus used in both the alternating-current and direct-current systems of distribution.

Alternating current has some properties that are not possessed by direct current, the most interesting one to us being that it can be raised in pressure without the use of a generator. The medium which is used

to raise the pressure of alternating current is known as a transformer. (See Figure 38.)

A transformer consists of a large body of iron around which are wound two coils of wire. When an alternating current is fed through one of these coils, following the principles already mentioned, we see that lines of force are set up in the iron around which this coil is wound. We have also seen that if the lines of force pass through a mass of iron about which there is a coil of wire, a current will be set up in this wire; therefore, when an alternating current is fed into one of the coils of a transformer another current is induced in a second coil. It should be noted that the pressure of the current thus generated is greater or less than that of the current passing through the first coil, according to whether the number of turns in the second coil is greater or less than the number of turns in the first coil. Transformers usually are built with a definite ratio between the number of turns in the two coils, so that if current is fed in at a certain pressure it is known beforehand at what pressure it will be taken out of the second

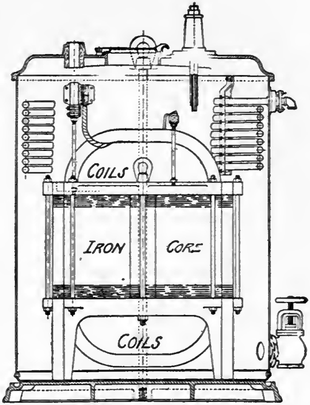


Figure 38—Section of Transformer.

coil. Thus it is seen that if there are alternating-current generators at the power station the current from these may be fed into a set of transformers and its pressure raised to a comparatively high voltage—say, 40,000 volts.

The Alternating-Current System.—Experience has shown that current can be transmitted over long distances with a comparatively small loss, if high voltages are used, and therefore, in System No. 2 (Figure 39), the general circuits include transformers for raising the voltage at the power station, a set of wires known as a transmission line for carrying the current to distant points, and other transformers connected with the ends of this transmission line which reduce the pressure so that it can be fed to the trolley wire at a voltage low enough to be used safely on the cars.

It should be noted that in this alternating-current system, commonly known as the single-phase system, there is no direct-current machinery. The types of motors used under the cars are so designed that they will operate on either direct or alternating current, and so far as the speed and propelling power are concerned very little difference will be noted in the movement of a car over lines supplied by these two methods of distribution.

Alternating-Current-Direct-Current System.— The method of distribution indicated as System No. 3 (see Figure 40), is a combination of the other two systems of distribution. It comprises alternating-current transmission lines as in No. 2, and direct-current trolley lines as in No. 1. The different parts of the system are as follows: Alternating current is generated and by means of transformers in the power station its pressure is raised to an economical point for use on the trans-

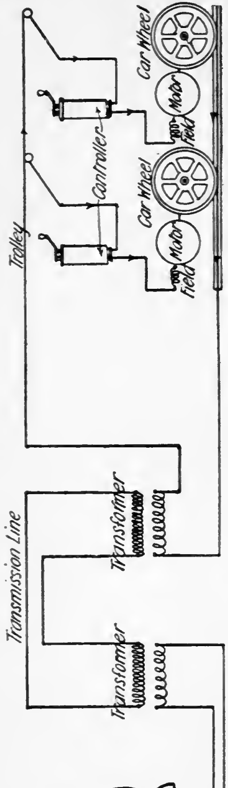


Figure 39—Path of Current in Alternating-Current System.

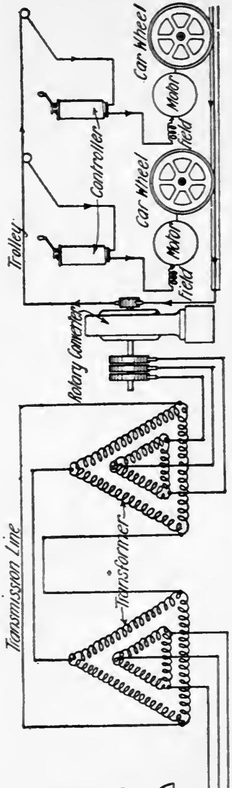


Figure 40—Path of Current in Alternating-Current-Direct-Current System.

mission line. This transmission line running along the trolley poles feeds a number of substations which, on the interurban lines, are located about 10 miles apart. Each of these substations includes in its equipment a set of transformers which reduces the transmission pressure so that the current can be fed into an alternating-current motor located in the substation building. This motor is directly connected to a direct-current generator which generates current suitable for operating the cars, usually at 600 volts pressure. By means of feeder cables the current from the direct-current generator is fed to the trolley and then to the cars. It passes through the motors and into the track rails, whence it returns to the negative side of the generator in the substations.

For the sake of simplicity and economy in construction, the armatures of the motor and the generator, which are used to convert the current, are sometimes wound on the same core and used in a single set of field magnets. When so combined the machine is known as a rotary converter (Figure 41). It differs little in principle or method of operation from the motor-generator set first mentioned in connection with substation apparatus. This system of transmission is known as the alternating-current-direct-current method of distribution, and is probably the most generally used at the present time.

To assure clearness it probably will be best to again state the three general methods of furnishing power to cars. The first mentioned, the direct-current system, uses only that kind of current which flows continuously in one direction. This system was the first to be used for propelling electric cars, and is by far at the present time the most generally used.

The second system, known as the alternating-current system, employs only current which alternates in the wire. Car motors for this type of distribution recently have been developed and many improvements made in their control apparatus, so that for long lines in the construction of which economy of transmission

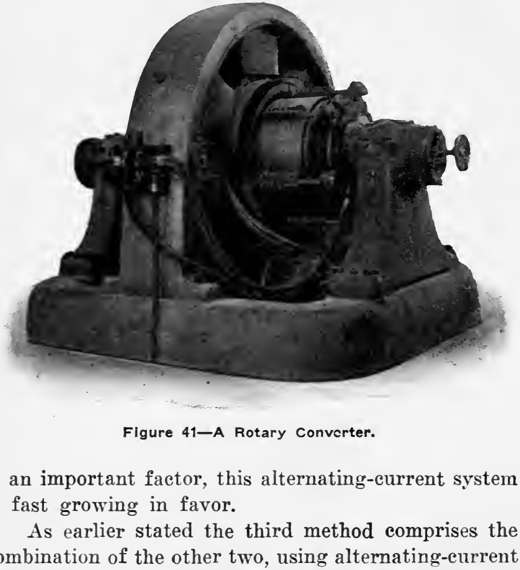


Figure 41—A Rotary Converter.

is an important factor, this alternating-current system is fast growing in favor.

As earlier stated the third method comprises the combination of the other two, using alternating-current machinery for generation and transmission and direct-current apparatus for the propulsion of the cars. At the present time practically all of our large city systems and a great majority of the interurban lines have their cars operated by this method.

CHAPTER IV.

OVERHEAD CIRCUIT AND THIRD RAIL.

In transmitting electric power certain precautions are necessary. The electric current has to be guided by means of a conductor, which in practice is generally copper wire, and, in order that the energy transmitted shall be wasted as little as possible, the conducting wire must be thoroughly insulated from the earth and from all other conducting bodies. It was found at an early day that there is a great deal of difference in the conductivity of different substances. Some conduct the current very easily, others less easily, and again others do not conduct the current at all unless it is forced through them under very high pressure. The first class of substances, which are known as good electrical conductors, includes all metals, and of the metals the best conductors are silver and copper. The last class of materials, which do not conduct electric current, are called non-conductors or insulators, and if a conductor is attached or supported upon a non-conducting substance, the conductor is said to be insulated. Thus, if we should lay bare electric wires in the ground we would receive but little current at the far end, because the earth is itself a conductor of electricity and would

return a greater part of the current to the dynamo. It is evident, therefore, that the conductor must be insulated from the earth and from all other conductors in order to transmit the current to a distant point where it is desired to use it.

Insulators.—Perfectly dry air is one of the best insulators known, while water containing dissolved salts and other impurities, as generally found, is an

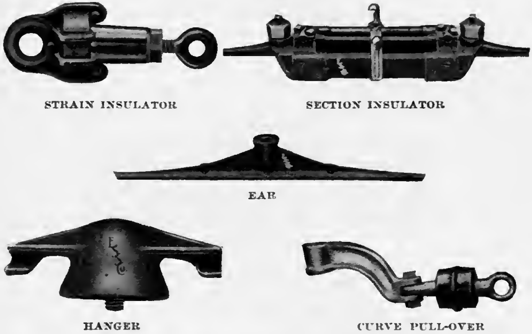


Figure 42—Overhead Fittings.

excellent conductor. There is little chance for current to escape from a wire supported on insulating material unless moisture, acids or dirt are to be found on the surface of the insulators, in which case a slight leakage through the dirt or moisture will occur. The best and most commonly used insulating substances are porcelain, glass, mica, rubber, dry wood, silk, shellac, paper and cotton.

The electric current has to be produced in most cases by operating a dynamo by means of a steam

engine, and this engine receives its energy from the boiler under which coal is burned. The energy located in the coal is utilized to evaporate the water in the boiler, and the steam so produced actuates the engine, which in turn operates the dynamo. The greater the waste in electricity, the greater will be the coal consumption. Therefore, the desire to avoid losses as much as possible, such as leakage on electric lines or faults or leakage on devices connected therewith, since they form part of the circuit the moment the current is allowed to pass into them. For this reason motors, controllers and other parts attached to the car are

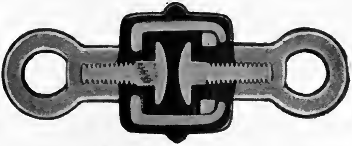


Figure 43—Sectional View of Strain Insulator.

carefully insulated, and the overhead conductor is held in position by insulators of hard rubber, glass, porcelain, compounds of mica, or other substances put into suitable shape under great pressure.

Some such insulators as used on electric railways are shown in Figure 42. In most cases they consist of two metallic parts which are separated from each other by a strong and thick layer of insulation. One metallic part is then connected to the conductor which is to carry the electric current, while the other is attached to a pole, or span wire. This latter may be regarded as connected to the earth, but the other end is insulated from such contact by the interposed layer of

non-conducting material. Figure 43 shows such an insulator in section disclosing its construction.

The circuits of most electric railways include the high-tension transmission line of alternating-current feed wires and the well-known trolley wire, such as are shown in Figure 44. Besides the trolley wire method of carrying current to the cars, there are the third-rail

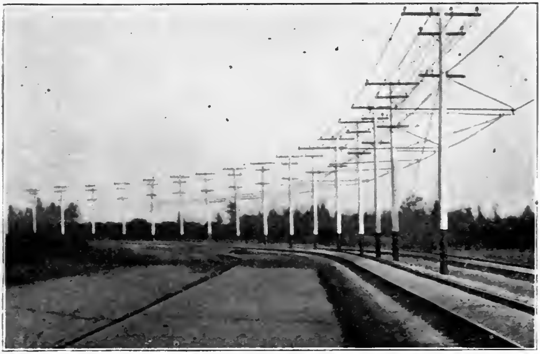


Figure 44—Trolley and High-Tension Wires.

system and the conduit system. This third-rail system has been mentioned before.

Third-Rail System.—The third-rail system is one in which a rail called the third rail is substituted for the overhead trolley. The third rail may be placed either between the two track rails or outside of them. The third-rail system is at the present time assuming considerable importance in the direct-current electric railway field, and this type of construction is adopted where heavy cars are made up into trains and operated

at high speed. The reason that the third-rail system is preferable to the overhead trolley in such cases is that the weight and speed of trains requires an amount of current which is too great to be collected by the overhead trolley wheels, owing to their very limited contact. In the third-rail system the sliding contact is maintained by means of a shoe which slides along the top or bottom of the third rail, and may be

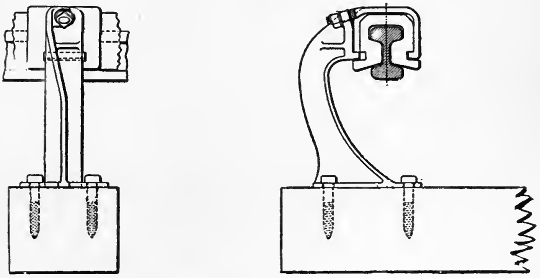


Figure 45—Bracket for Under-Running Third Rail.

given sufficient area to carry any required amount of current.

The first commercial installation of the third-rail system was on the intra-mural railway at the World's Fair in 1893. It was next adopted by the elevated roads of Chicago and afterwards on a branch line of the New York & New Haven railroad. The system was subsequently extended to various branches of the same road. It was next used on the Albany & Hudson Ry., after which it was installed on the Aurora, Elgin & Chicago Ry. There have since been built a large number of such systems. The third rail, as shown in

Figure 45, is elevated about three inches above the level of the track rails, and is supported on insulators resting on the ties. In this country the third rail is always located outside of the track rails. In the earlier third-rail systems, insulators were made of wood, but it has been found that after a year or two of service the wood absorbs sufficient moisture to partly short-circuit the insulator, and cause considerable loss through leakage.

Aside from the location of the supply conductor, there is no difference between the third-rail and the overhead system, so far as the circuits upon the car are concerned.

The third-rail system is applicable only to roads running upon a private right of way, and is especially adapted to the operations of cars in trains, which requires a larger amount of current than can be collected by one trolley wheel. Shoes are placed at the journal boxes of all the cars, so that on a long train the current is collected at a number of different points. Where the road crosses a highway the third rail is broken, stopping at each side of the crossing, and the car is allowed to drift over the gap without current. The continuity of the third-rail circuit is secured by attaching an underground cable between the two ends of the third rail, and these ends are built with a downward curve so that the shoes, which can only drop slightly below their normal position, do not make violent contact with the rail, but ride up on the curved portion.

Conduit System.—The conduit system is one in which the conductors are carried in a conduit under the surface of the street similar to a cable railway conduit. Unlike the other system described the con-

duit system does not make use of the tracks for a return circuit, but instead both the positive and negative conductors are supported on insulators fastened inside of the conduit. The current is taken from these conductors by means of a trolley extending down through a slot in the surface of the road. This underground trolley is called a plow. The conductors are generally composed of copper bars and the plow contains sliding contact pieces which rest on these bars. One side of the plow collects the current, which is led to the controllers and motors, after which it passes again to the plow contact which is in connection with the return circuit.

This system is in use in New York City and Washington, D. C., and in a few European cities where overhead conductors are prohibited. It is very expensive to build.

Storage-Battery Cars.—A storage-battery car is one which has electric current stored in cells or batteries in the car, which supply current to the car motor. Such a car can run on any railroad track and requires no wires or conductors outside of itself. The storage cell consists of plates of lead immersed in acid, and these cells are charged at the power station by putting them in circuit with a dynamo, the electric current causing chemical changes in the lead. These changes represent a certain amount of electrical energy, which is given out when the batteries are connected to the car motors. The battery merely supplies current for the car and the controllers are similar to those on trolley cars, and the method of operation is the same. Storage-battery cars are not very extensively used, as the cost of operation is considerably higher than that of trolley cars. This is chiefly due to the batteries, which

are expensive to install and which wear out rapidly under the severe conditions of street railway work.

Electric Locomotives.—For the purpose of moving long trains of cars, switching freight cars and other purposes where the power required is so great that the motors cannot be mounted on the trucks of ordinary cars electric locomotives are used and current is taken from an overhead wire or a third rail, as with a trolley car. These locomotives (Figure 46) are equipped with motors of large capacity and their frames are very heavy so as to secure sufficient adhesion to the track

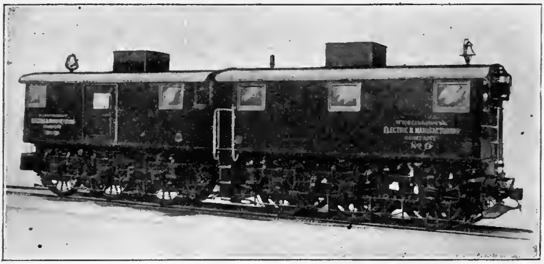


Figure 46—Large Electric Locomotives.

to pull very heavy loads. The controllers and other apparatus on electric locomotives are similar to those on cars of ordinary size, being merely larger and heavier to accommodate the larger current used.

In the great projects now under way tending toward the electrification of the more densely traveled lines of our larger steam railway systems, the electric locomotive plays an important part. Such locomotives are built with steel bodies and trucks equipped with motors that give the locomotive far greater hauling

capacity than can be had with steam locomotives. Many interurban railways also use electric locomotives for handling freight cars. It should be remembered that the principles on which the locomotive depends for its operation differ in no way from those governing the operation of an electric car.

Overhead Trolley.—Overhead trolley may be divided into two general classes, according to the method

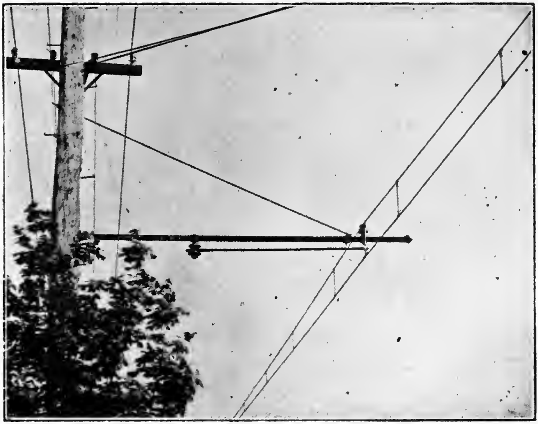


Figure 47—Trolley Bracket and Catenary Trolley Construction.

of suspension. The first and more widely known is the common flexible suspension. The second is known as catenary construction. (Figures 47 and 48.)

Each method of suspension requires for the support of the overhead material one or two lines of poles. When one line of poles is used iron brackets are required to support the trolley wires over the center of

the track, and when two lines of poles are used span-wires across the track from pole to pole support the trolley wire. The trolley wire may be either round or grooved in section. The round wire is supported by means of soldered or clinched ears and the grooved wire by means of mechanical clamps which hook over its upper part. The ears in turn are held by what are known as hangers, either insulated or non-insulated, depending upon whether or not a strain insulator is placed in the span or supporting wire. The span wires usually are composed of stranded cable which has been galvanized to prevent its rusting.

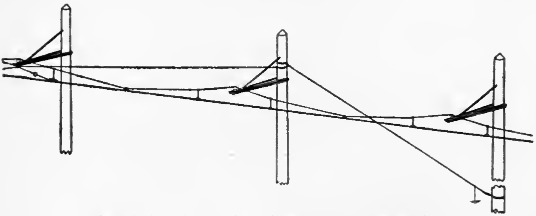


Figure 48—Anchoring Catenary Construction.

Catenary Construction.—It is essential for high-speed operation that the trolley wire be supported in a plane parallel with that of the track rails. It is also essential that there be very few sharp bends either horizontally or vertically in the copper wire. With the ordinary type of span or bracket construction such kinks do occur, and with a car operating at high speed there is a tendency for the wheel to break contact or leave the wire at the bends which occur under the supports. The reason for these bends existing is because each hanger is called upon to support a section of the trolley wire about 100 feet long. To overcome this

defect the catenary type of trolley construction is now being widely used.

The essential parts of this catenary method of construction include a messenger wire, supported at points about 125 to 150 feet apart, these supports

Figure 49—Catenary Construction with Bridges.

being either span wires or brackets, as in the ordinary type of construction, but including an insulator on which the messenger wire rests, so that no path is afforded the current from the steel messenger cable to flow through the bracket or span wires and

thence to the ground by way of the poles. From this messenger wire the trolley is supported at a fixed distance above the track by means of frequent vertical hangers. Inasmuch as the messenger itself is insulated from the ground it is wholly unnecessary to use insulated hangers between the trolley wire and the messenger; in fact, the steel messenger cable supplements the trolley wire as a conductor of electricity. It

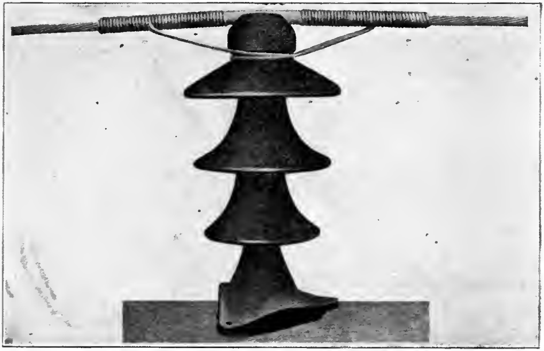


Figure 50—High-Tension Insulator and Tie Wire.

is thus seen that with the vertical hangers spaced at intervals of from 10 to 25 feet the trolley wire can be supported with practically no kinks in its under surface. Thus it is possible to operate the cars at high speeds and use either the ordinary trolley wheel or one of the sliding-contact type which will be described later.

The catenary type of construction is used most frequently with those lines operating at high voltage.

This choice is made because the trolley wire and messenger can so easily be insulated for high voltages. It is also an economical type to use because with the aid of the strong steel messenger cable the distance between points of support may be increased and the number of poles required greatly lessened. In the project of electrifying the New York New Haven & Hartford lines near New York City, steel bridges are used to support the messenger cable, as shown in Figure 49.

Transmission Lines.—For the sake of reliability of service the transmission lines which carry the current from the power station to the substations, as earlier described, should be built in a very substantial manner. These lines as now built comprise wooden or steel poles and steel towers, some of the longer lines being supported on steel windmill towers. At the top of each pole or tower are crossarms of wood which support at their extremities steel or wooden pins carrying large insulators. These insulators (Figure 50) must be made very carefully and of such dimensions and materials as will prevent any leakage of the current between the power wires and the poles.

CHAPTER V.

THE ELECTRIC RAILWAY MOTOR.

We are now ready to look into the details of an electric railway motor. In Chapter II were explained the principles on which all dynamos and motors are built. It was found that a motor is simply a magnet in which the magnetism is produced by the electric current, and in which one part, called an armature, is caused to revolve by magnetic attraction between it and the poles of other parts, called the field magnets. It was also learned how the electric current is transmitted through wires, and what precautions are necessary to insulate or confine it to the proper wires or conductors.

Let us go more into the details of the internal working of the armature of the dynamo or motor, and show the reason why in one case large engines are used to produce the electric current, while at other times the armature will turn itself and give out energy. In Figure 29 is shown an armature complete. It consists of a shaft on which is mounted an iron core closely wrapped with wire. The ends of the wire coils are connected to the contact terminals, called the commutator, on which the brushes rest to collect the current. An armature is represented in diagram in Fig-

ure 51. The iron armature core A is shown in the form of a ring. The winding B is uniformly wrapped around the core, and every three turns a wire is led to the commutator C, which is divided into eight parts because the winding shows eight coils. The number of coils varies on different kinds of armatures.

Commutator and Armature.—The commutator consists of copper bars insulated from one another by mica. These bars form the ends of the armature coils. The bars are exposed to wear by rubbing contact, and

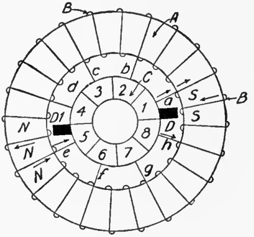


Figure 51.

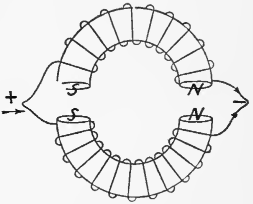


Figure 52.

therefore are made heavier than the wires so as to last a long time, and to be detachable when worn out. On the commutator rest the brushes D, D1. If the armature is traversed by a current entering at brush D, as for instance when it is used as a motor, the current passes to segment 1, and from there through connecting wire, A, to the armature wire proper. Here it has a double pass, as shown by the arrows. Half the current will follow the direction indicated by the arrows on the upper half of the ring, and the other part of the the current will follow the wires wound on the lower half of the armature core. The two currents unite

again in the wire, E, enter segment 5, pass through brush D1, and leave the armature. This flow takes place in whatever position the armature may be. For instance, assuming the brushes D, D1 stationary and the armature turning; if the armature had turned so far around that segment 2 would be under the brush D, then segment 6 would be under brush D1. The current would go to the armature winding through b and leave it by way of f. In this way each one of the segments and connecting wires has to perform its work in succession. The current in going around the core makes a magnet out of the iron, as indicated by the letters N, S.

For the sake of convenience in understanding, the armature core may be also considered divided into two half rings, as in Figure 52, the upper and lower; then the current flowing around the upper half makes it a magnet, and similarly the current in the lower half will make that half become a magnet. The poles are marked N and S. The poles caused by each half of the current are indicated on the ring. An N pole on one side and an S pole on the opposite side in each half as produced, and both together make again one N pole and one S pole, but of double the strength. As long as the brushes stand in this position the magnetic poles will stay in space in the same position, however much the armature may rotate, because just as many turns are leaving the brush on one side as are brought under it from the opposite side.

The iron ring wrapped with the armature wire represents in reality two half-circular magnets butting together with similar poles. Whether these are curved as in Figure 52 or have another form, for instance, being straight bar magnets, does not alter anything in the

nature of the armature. Nor is there, as far as principle is concerned, any difference between a ring armature, shown in Figure 51, and a drum armature. An armature made for a street railway motor is generally made of thin discs mounted in a compact way on a shaft (Figure 53). All the wire in this case has to be applied externally. It cannot be threaded through the center as in Figure 51, but the results are the same. Figure 54 is a diagram indicating a railway motor with an iron core made of discs and the magnetizing copper wire wound all around the surface.

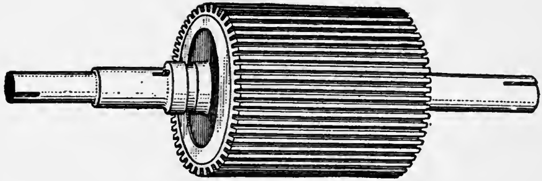


Figure 53—Armature Core.

The diagram represents the armature in section. Now suppose the brushes to be set as they are in Figure 51, then the current flowing in the coils with which the armature core is wound will cause N and S poles in the armature as shown. Current is also sent through the coils on the field magnets, causing N and S poles in the magnet as indicated. It will be evident that the S pole of the armature will endeavor to place itself in front of the N pole of the field magnet, being attracted by it and at the same time repelled by the S pole near it. Similarly the N pole of the armature will try to get in front of the S field pole, being attracted by this pole and repelled by the N pole; but, as the brushes are sta-

tionary, the magnetic poles S and N of the armature remain fixed in space between the poles, while the conductors carrying the current and the core on which they are wound are turning in the direction of the arrow as long as a current is conducted into the armature.

In a motor, therefore, the electrical energy furnished by some outside source causes rotation capable of developing mechanical energy. In a dynamo it is just the opposite. There is no electrical energy given: it has to be produced. The wire coils passing in front of the magnet poles generate current.

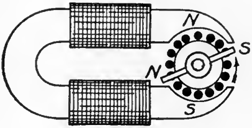


Figure 54.

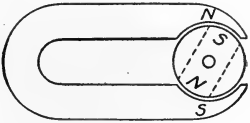


Figure 55.

Figure 55 illustrates this action. The field magnet N S changes the armature into a magnet with the poles as indicated, the S pole of the armature approximately facing the N pole of the field and the N pole of the armature nearly facing the S pole of the field magnet. There exists mutual attraction between the armature and the field magnet. To generate a current, the armature must be turned between the energized field magnet poles, which is equivalent to attempting the pulling away of the armature poles from under the field poles. This we know from the first experiment mentioned in the book means the expenditure of energy.

Parts of Railway Motor.—We can now look more intelligently at the parts of a railway motor than we

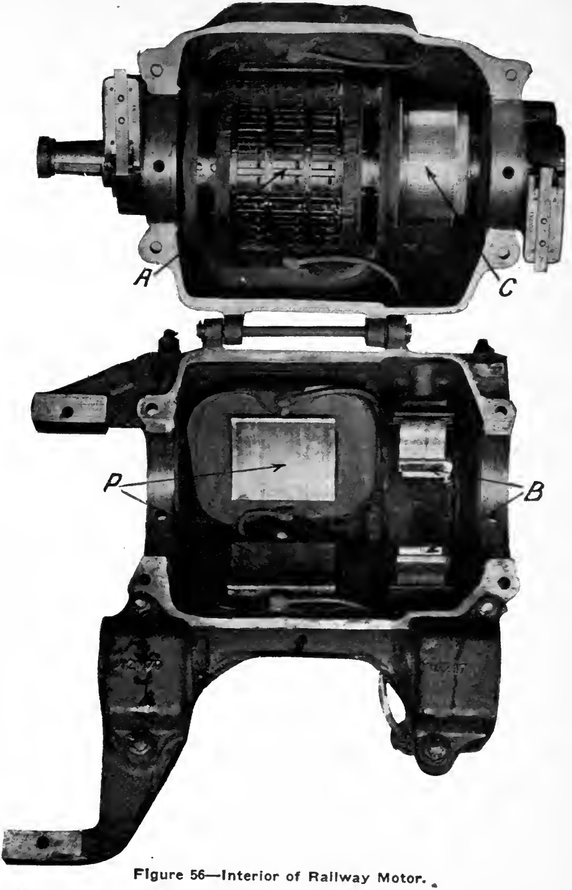


Figure 56—Interior of Railway Motor.

could at first. Figure 56 shows a railway motor with its frame opened, giving a view of its interior parts. The armature, A, is mounted upon a shaft and at one end of the armature is the commutator C, consisting of a cylinder of insulated copper bars, to which the ends of the armature coils are connected. Surrounding the armature are four field magnets, or poles, P, around which are wound coils of wire to magnetize them for the purpose previously explained. The brushes, B, conduct the current to and from the armature through their contact with the commutator. These brushes consist of carbon blocks which are held in brush holders (Figure 57) and pressed against the commutator by springs. The principal parts of an electric railway motor are: The armature, which has been described and is mounted on a steel shaft; the shell or case, which is a large box-like casting of soft steel supporting on its interior the field magnets, and the gears which transmit the turning power from the armature shaft to the car axle.

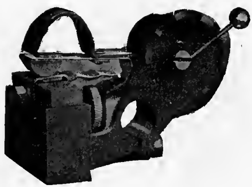


Figure 57—Brush Holder.

The path of the current through the motor is as follows: Starting at one of the brushes the current passes through all the coils of wire upon the armature, beginning at whatever commutator bar the brush happens to rest upon, and comes out upon another commutator bar under the second brush. From this brush the current is led through all the field coils wound around the poles surrounding the armature, and this completes the circuit through the motor. With the

current flowing through both the armature and the field coils, both the armature and the field become magnets, and each attracts the other in such a way as to cause the armature to turn as previously explained. To reverse the direction in which the armature revolves, which reverses the direction of the car, it is only necessary to change the direction in which the current flows through the armature, allowing the current to flow through the fields in the same direction as before; or, we can also

Figure 58—Motor on Axle.

reverse the direction of revolution by permitting the current to flow in the same direction through the armature and reversing its direction through the field coils. If the armature current is reversed the magnetism in the armature is reversed, the north pole becoming a south pole and the south pole a north pole. In order to reverse the current in the armature the wires from the armature brushes are led to the controller independently from the terminals of the field coils, so that the connections of the armature terminals can be reversed

at the controller when it is desired to reverse the direction of rotation of the motor. For this reason there will always be at least four wires leading out from the motor.

An electric railway motor mounted on an axle between the car wheels is shown in Figure 58. For the sake of clearness one pair of wheels and axle have been taken away from the truck. The motor consists

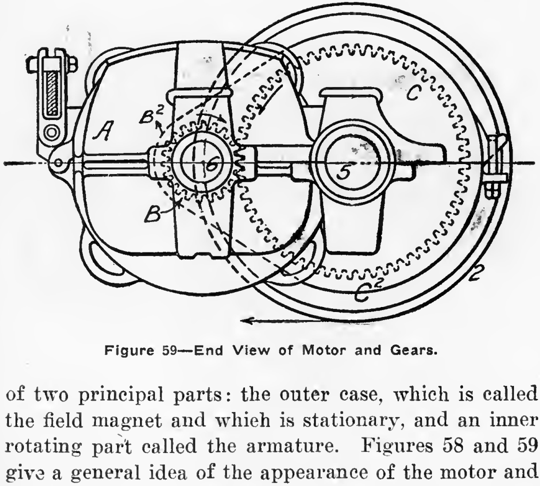


Figure 59—End View of Motor and Gears.

of two principal parts: the outer case, which is called the field magnet and which is stationary, and an inner rotating part called the armature. Figures 58 and 59 give a general idea of the appearance of the motor and may be referred to together. On one end of the armature shaft 6 is keyed a pinion B, as shown in Figure 59, but in service the pinion and the gear into which it meshes are covered by a casting as B^1 C^1 in Figure 58. This pinion meshes with a gear which is fastened on the car axle. The car axle passes through the bear-

ing 5, as shown in Figures 59 and 60. Both solid and split gears (Figures 61 and 62) are used. The split gears are more easily handled for repairing, but the solid gears, which are pressed on the axles by hydraulic power, wear longer.

The manner in which the car is propelled will now be made clear. In starting the car a current is sent into the motor which causes the armature to revolve

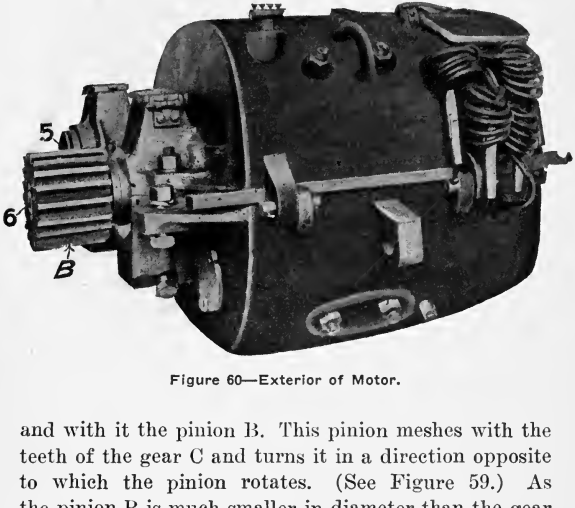


Figure 60—Exterior of Motor.

and with it the pinion B. This pinion meshes with the teeth of the gear C and turns it in a direction opposite to which the pinion rotates. (See Figure 59.) As the pinion B is much smaller in diameter than the gear C, the car axle to which C is rigidly attached makes a less number of revolutions than does the pinion which drives it. In this way the power developed in the motor is transmitted through the gears to the car axle

and the speed of the latter is much less than that of the motor armature.

Returning to Figure 59, if the power admitted to the motor turns the armature shaft 6 and pinion B in the direction indicated by the arrow, then the gear C will revolve in the opposite direction and the car wheel 2 will move from right to left as indicated by the arrow. The function of the casing B^1 is to protect the pinion and gears from dirt and mechanical injury. Some gear

Figure 61—Solid Gear.

Figure 62—Split Gear.

cases are made of wood and steel, as shown in Figure 63. If filled with a heavy grease the gears are thus lubricated and preserved, and at the same time the noise which they make in running by this means is greatly reduced. In all of the motors illustrated a lid will be noticed over the commutator end of the frame where the brushes are located. These lids are readily removed, and their object is to facilitate inspection of the commutator and brushes.

It will be noticed that all of the motors illustrated have their field casings designed so as to entirely en-

close the interior parts, and all the joints of the outer frame are made tight enough to be practically waterproof. Water and dirt would readily be thrown into the motor from the car wheels if the parts were not tightly enclosed, but by having the motor case close tightly the windings are protected from water, which would injure them.

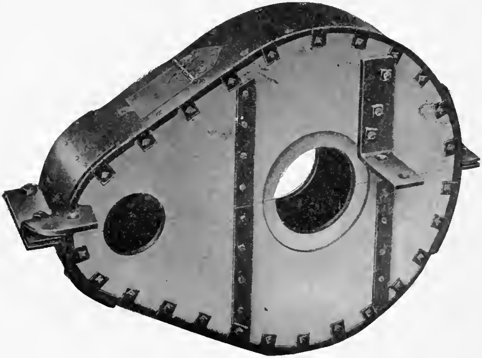


Figure 63—Gear Case.

Figures 64 and 65 show two views of a car motor. Figure 64 shows the frame closed about the armature ready for operating. Figure 65 shows the lower frame of the motor dropped, with the armature in the lower position. This method of dividing field magnets horizontally through the bearings and fastening the lower part at one side by means of hinges provides for the inspection and repairs of the interior parts of the motor.

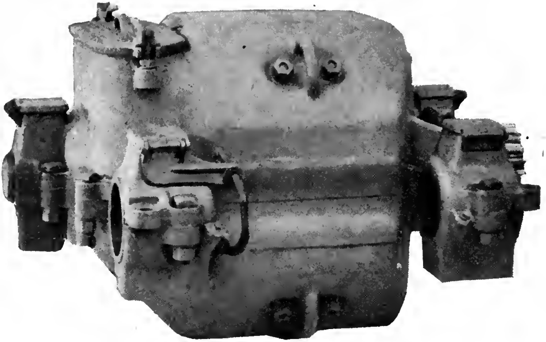


Figure 64—View of Motor from Axle End.

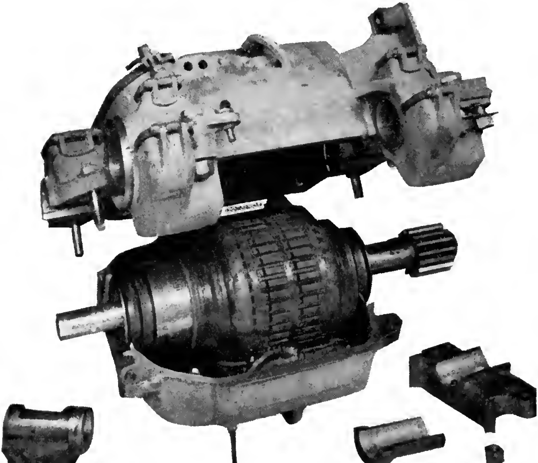


Figure 65—Motor with Case Open.

Motor Suspension.—In supporting motors upon car trucks one side of the motor is held in position by the bearings resting on and around the car axle. The other side of the motor is not usually fastened rigidly to the

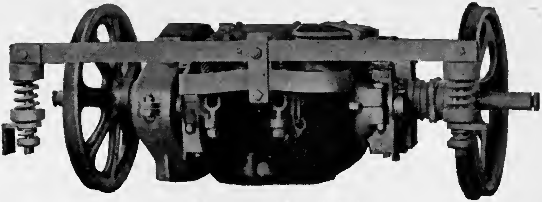


Figure 66—Cradle Suspension.

frame of the truck, but has springs placed at some point between the motor and the frame in order to avoid the sudden jar which would be occasioned in starting the motor if it were rigidly connected. These springs also serve to greatly increase the life of the gear wheels, as part of the shock in starting is taken up by the

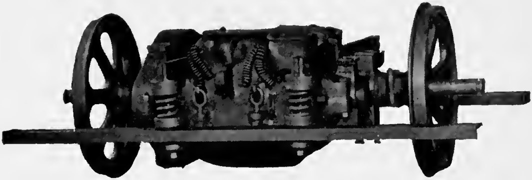


Figure 67—Parallel Bar Suspension.

springs, without which the teeth would be liable to be stripped from the gears. Figures 66, 67 and 68 represent the same motor with different styles of suspension.

Figure 66 shows what is called the cradle suspension, which consists of an iron bar resting on heavy springs which in turn rest on the truck. This method is designed to relieve the motor bearings of the weight of the motor, which being suspended in the line of its center of gravity is supported without undue strains. Figure 67 shows the parallel bar suspension and Figure 68 the nose suspension. The latter is the one most commonly used.

Types of motors differing in some respects from those previously illustrated are shown in Figures 69

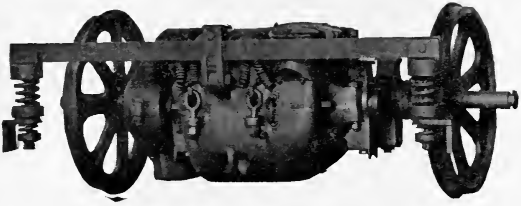


Figure 68—Nose Suspension.

and 70. Figure 69 is known as the box-frame type and differs from the split-frame type in that the magnet frame is cast in practically one piece, forming a cube with well-rounded corners and large openings at each end into which the frames carrying the bearings for the armature shaft are bolted. The armature is put in place or removed through these end openings in the frame.

Motors of this type are mounted or moved from the truck by means of a crane from above when the truck is out from under the cars, and no track pit is re-

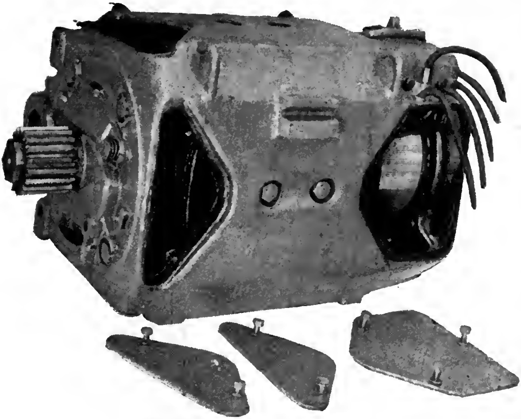


Figure 69—Box-Frame Motor.

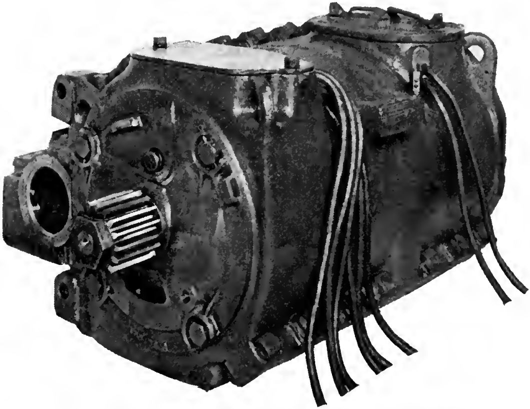


Figure 70—Motor with Diagonally Split Frame.

quired. In order to facilitate removing the armatures from these motors a special tool is provided, upon which the motor is mounted. The armature shaft is centered on this tool and by removing the bolts from one of the frame heads and moving the motor frame to one end of the tool by means of the hand wheel, the armature is left entirely exposed and mounted upon centers, where it may be readily inspected or repaired. A more recent way is to stand the motor case on end,

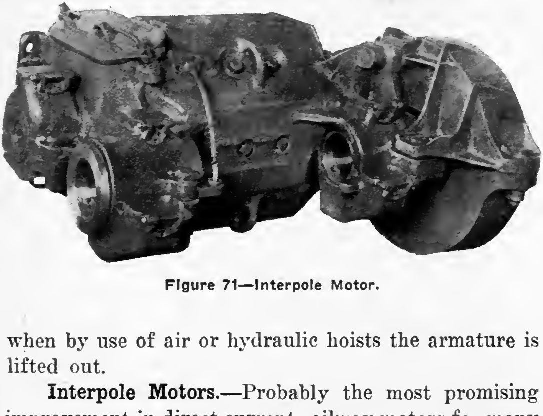


Figure 71—Interpole Motor.

when by use of air or hydraulic hoists the armature is lifted out.

Interpole Motors.—Probably the most promising improvement in direct-current railway motors for many years is the introduction of the interpole or commutating pole motor. The commutation of high-voltage current in railway motors has always been a most difficult problem for the designers of such machinery to solve and the care of commutators and brushes forms no small part of the duties of the mechanical and electrical force of a railway company.

Sparking on a commutator bites away a small amount of copper and carbon at each spark, but does not affect the mica between segments. If the sparking is continued, the copper is soon eaten down, thus leaving the mica sticking up. This "high mica" in turn makes the sparking worse and causes a general roughening of the commutator, flattening of the bars, etc., with consequent rapid wear of the brushes, which fills the motor with carbon and copper dust, and sometimes causes it to flash, ground, etc. Milling down the mica below the copper prevents some of this trouble, but does not go to the root of the matter.

In service a railway motor does not run continuously with power on, but the time that it is operating under load is varied by a certain amount of coasting and stopping. During this no-load running the roughening which has been caused by the action of the current is partly corrected by the scouring and polishing effect of the brushes without load. In many cases the scouring action predominates so that the commutators remain bright and clean and take on a good polish.

The purpose of commutating poles is to reduce sparking. The commutating pole is an intermediate pole of small dimensions, placed between the main field magnet poles. It is used for reversing the direction of the current in the armature coils when they are short-circuited by the brushes. Thus, by magnetically inducing a current of proper direction in the short-circuited coils, the sparking at the commutator, resulting from the "kick" of the short-circuited coils, is avoided. Since the direction of the current in the commutating pole coils is reversed when the current in the armature is reversed, they are equally effective when the motor is reversed.

These motors are manufactured in six sizes, ranging from 50 to 200 horsepower. They are built for a standard of 600 volts.

The field magnet frames of these motors are similar in design to those of the standard railway motors, with the exception that the commutating poles are inserted between the main pole pieces, as shown in Fig-

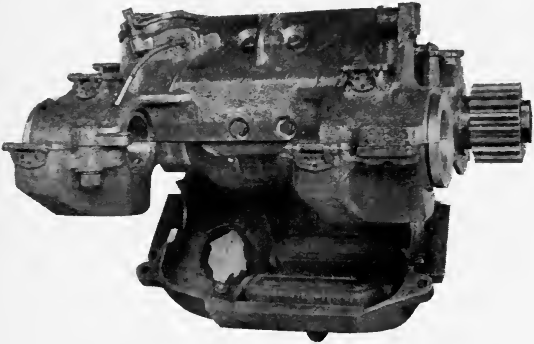


Figure 72—Interior of Interpole Motor.

ure 72. The frames are made in both the split and box types.

The Single-Phase Motor.—The single-phase railway system accomplishes the same results in car movement that are secured by the use of direct-current equipments, but it does this in many cases with less first cost, less operating expense, increased flexibility and greater simplicity.

At the substations the alternating-current power which is received from the generators is merely re-

duced in voltage by transformers and supplied at once to the cars, instead of being changed into direct current by transformers and rotary converters. The equipment of such a substation is quite simple and may be left without attendants.

One of the fundamental characteristics of alternating current is the readiness with which it can be transformed from one voltage to another. Where alternating-current motors are used, therefore, it is not necessary as with direct current to supply power to the cars at the voltage of the motors, but by the use of a transformer on the car the voltage of the trolley and that of the motors may have any desired ratio. As it is entirely feasible to employ a voltage of 11,000 (which permits the distribution of a large amount of power with a very small current) on a properly insulated trolley wire, the single-phase system affords means of operating even the heaviest cars or trains from an ordinary trolley wire of moderate size with no additional feeders.

The single-phase railway motor does not involve any particularly new or mysterious principle, but depends for its operation upon an extension of the well-known fact that reversing the current at the terminals of a series direct-current motor does not reverse the direction of rotation or interfere with the operation. This principle holds good no matter whether the current is reversed once every hour or once every minute. Since an alternating current gives merely the same general effect as a very rapid and continuous reversal of a direct current the ordinary direct-current railway motor rotates if suitable alternating current is applied to it.

The single-phase motor (Figure 73) ordinarily is

wound for a voltage of from 200 to 250 instead of 500 or 550, as in the case of direct-current motors. The larger currents which must be handled on this account necessitate greater brush capacity than in direct-current motors, so that four brush arms ordinarily are required with a four-pole motor or six with a six-pole motor.

The standard trolley voltage for single-phase op-

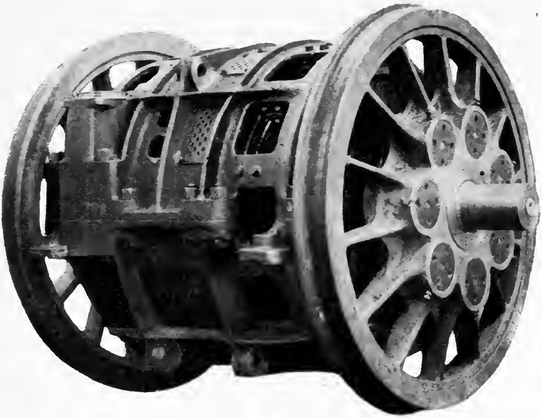


Figure 73—Single-Phase Motor.

eration is 6,600, although voltages of 3,300 and 11,000 are also employed in some cases.

To reduce the trolley voltage for use at the motors an oil-insulated, self-cooling "auto-transformer" is used. As with direct-current motors, the speed of the single-phase motor varies with the voltage at its terminals, and the motor is controlled in this way. In order to get a variable voltage for this purpose, how-

ever, it is not necessary, as in direct-current practice, to change the grouping of the motors, or to introduce resistance into the circuit, but simply to connect the motors to different taps on the auto-transformer.

The qualities which make the single-phase motor suitable for operation on alternating current make it operate equally well on direct current of the proper voltage. It is often desirable to obtain the benefits of single-phase operation with cars which for a part of their route must run over the same tracks and use the same power as direct-current cars, and by connecting two or more single-phase motors in series for such operation they can readily be arranged to run from a 550-volt trolley wire, as well as from a 6,600 or other high-voltage one.

CHAPTER VI.

CAR WIRING AND PARTS.

We will now trace the electrical circuit through the car. The current, as we know, comes from the power station through the feed wires and trolley wire, and flows through the trolley wheel down the trolley pole to the trolley base.

Figure 74—Roller-Bearing Trolley Base.

There are many styles of trolley bases. In Figures 74 and 75 two forms are shown. The trolley wire is generally attached to the iron base below. The springs are employed for the purpose of causing an upward pressure on the trolley pole, which is not shown. The pole can be removed from the trolley base and is held

adjustably in a socket. A great range of movement is necessary in the springs and trolley pole, as the trolley wire, suspended in the air, cannot be held at the same height over all the course of travel. For instance, at railroad crossings it is placed much higher so as not to interfere with the railroad service and brakemen who may be standing on the roofs of the cars; again it may be much lower in other places, such as bridges and tunnels.

One type of trolley base, shown in Figure 74, is mounted on an anti-friction turntable, which consists of four roller-bearing wheels, revolving between chilled

Figure 75—Trolley Base and Tension Springs.

surfaces, above and below. It is self-oiling and weatherproof in every respect and is also constructed so that should the pole be turned over in the opposite position, the tension would be the same. The sleeve in which the trolley pole is secured is two feet long, which length gives the trolley pole a reinforcement. The base is constructed so as to lock down and permit of changing the pole while in a horizontal position. The trolley pole is a long iron pipe-like pole on the end of which is located the "trolley." This trolley wheel, which consists of brass or special metal, is generally a small, narrow wheel with projecting flanges. On in-

terurban roads where cars are run at high speeds larger wheels, six inches in diameter, are used.

Pantagraph Trolley.—For use on high-speed roads operating at high pressures a pneumatically operated pantagraph trolley has been devised which can readily be raised or lowered by the motorman without leaving his cab. In trains of several motor cars, moreover, the trolleys on the entire train may be simultaneously controlled from any one point. This trolley is normally held against the wire by means of a spring, but is lowered and automatically locked down by the application of compressed air. Application of the air to another point will then unlock the trolley and allow it to rise.

Figure 76—Sliding Bow Trolley.

In the types of trolley shown in Figures 76 and 78 the current is collected by a rubbing or sliding contact bar.

Third-Rail Shoes.—Where the third-rail method is used for distributing the current along the track to the cars as we have described in Chapter IV, there are shoes provided to make an electrical connection between the car wiring and the third rail. These shoes

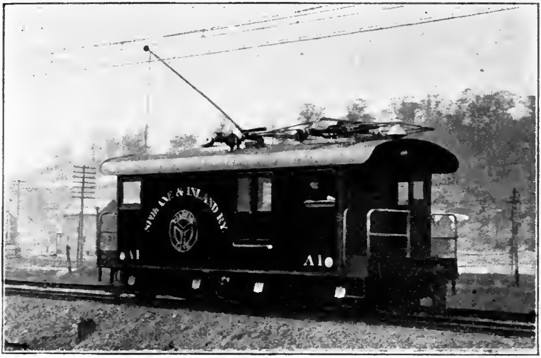


Figure 77—Pantagraph Trolley Lowered.

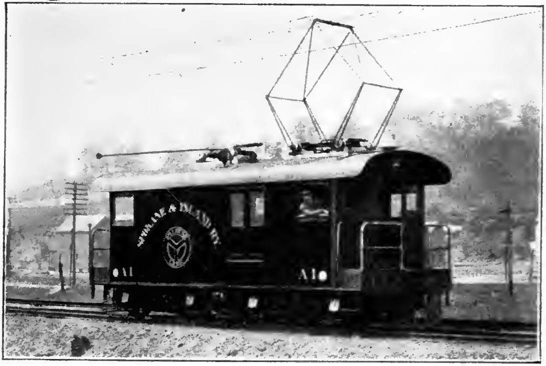


Figure 78—Pantagraph Trolley Raised.

are mounted on a bar (Figure 79), which is fastened between the two journal boxes so that it does not rise and fall as the car moves over rough track, but always remains the same distance from the track rail and the third rail. The shoe is of such a shape and size that when held by springs or its own weight it makes a

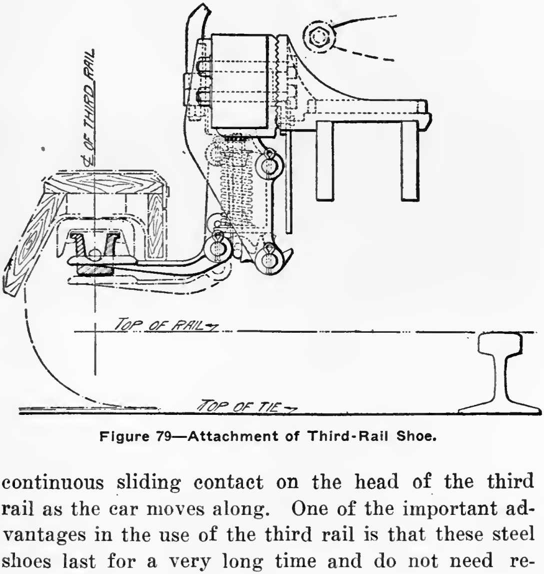


Figure 79—Attachment of Third-Rail Shoe.

continuous sliding contact on the head of the third rail as the car moves along. One of the important advantages in the use of the third rail is that these steel shoes last for a very long time and do not need renewing as often as trolley wheels. There is also another advantage—that no attention need be paid to the shoes by the car crew when it is desired to switch the car from one track to another or to back it in the yards.

All current collectors, of whatever type they may be, are insulated from the car body or trucks and the path of the current from the connections with the third-rail shoe or the sliding pantagraph trolley is the same as that from the ordinary wheel-and-pole trolley.

Main Switches.—From the trolley base a wire conducts the current to the canopy switches or circuit-breakers over the platforms and passing through these

Figures 80 and 81—Overhead Circuit-Breaker.

it flows through another wire, generally concealed in a corner post of the car, to a fuse box. The canopy switch (Figures 80 and 81) is also sometimes called the main motor switch, the overhead switch or the auxiliary switch. These switches are generally provided with what is known as a blow-out magnet coil, for the purpose of blowing out the arc when the switch is opened.

Automatic circuit-breakers have recently been used to a large extent to take the place of the fuse and canopy switch. They are preferable for a number of reasons, the chief of which is that they may be ar-

ranged to break the circuit when the current exceeds any predetermined amount with much more accuracy than a wire fuse, and they are thrown into circuit again simply by the movement of a handle without the necessity of replacing any of the parts, as with the fuse. There are a number of circuit-breakers on the market, all designed practically upon the same principle, one of which is shown in Figure 82.

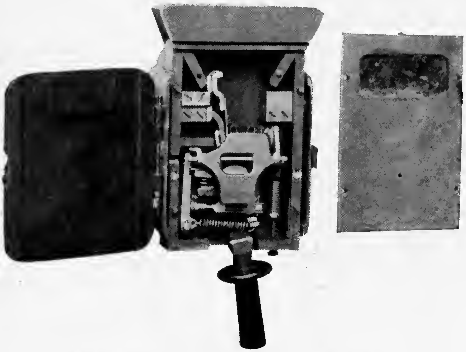


Figure 82—Circuit-Breaker Cover Open.

The principal part of the automatic circuit-breaker is a switch which closes against a spring, and which is held in its closed position by means of a trip. In the circuit of the machine is placed a magnetic coil, the purpose of which is to attract an armature whose movement releases the trip, permitting the spring to throw the contact surfaces apart and break the circuit. The cause of the armature being attracted and the trip released is this: The magnet coil is so wound that with a normal amount of current passing through the magnet

is not strong enough to attract the armature, but the moment an excessive amount of current is used the strength of the magnet is correspondingly increased, so that the armature is attracted and the trip released, which opens the circuit.

Fuses.—The next piece of apparatus in the circuit is the fuse box, which is a device for protecting the motors from an excessive flow of current. All of the current flowing through the car motors passes through one of these fuse boxes, of which there are several styles on the market. The simplest fuse consists of a piece of soft wire generally made of some alloy of lead having a low current carrying capacity. This piece of fuse wire will melt and open the electric circuit whenever the current flowing through the motors is of such an amount as might burn the insulation on the coils of the armature or the field magnet. When too much current is permitted to flow through any wire it becomes heated, and the greater the amount of current the hotter the wire becomes. If, therefore, something should happen on the car to allow too much current to flow through the motors the wire upon their armatures and fields would become heated so as to burn the insulation upon them, and eventually would be melted if the circuit were not protected with a fuse which would melt when the current exceeded a certain safe amount. The fuse is frequently a short length of metal connected between two binding posts, and of a material that will melt at a very low temperature, although sometimes a small copper wire is used. When copper is used it must be of a size much smaller than any of the other wires on the car, so that it will melt before any other of the wires in the circuit can get dangerously hot.

In addition to the bare wire fuses just described, there are various covered fuses such as those types shown in Figure 84 and Figure 85. These enclosed fuses have a fusible conductor which is enclosed in a tube, and around the conductor is a special filling which prevents any arc or. flash under short circuits. A fuse of this kind is a great improvement over the old-fashioned bare wire fuses. They do not blow with the loud report and heavy flash which accompany the blowing of a bare fuse. They are also of advantage in not blistering the varnish and paint

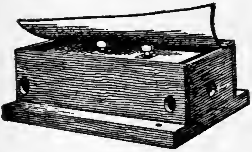


Figure 83—Open Fuse.

Figure 84—Closed Fuse.

of the car, which frequently happens with the uncovered fuse. Another advantage of these fuses is that they are inserted in the fuse box by simply pushing the tube into its seat between clamping springs, and there are no thumbscrews, the manipulation of which in the old kind is a difficult matter in severe weather.

Lightning Arresters.—The next device on the car to which the current is led is the lightning arrester. This is a device to deflect lightning from the circuit to the ground before it has an opportunity to reach the motors or other electrical apparatus on the car. There

is a strong tendency for a lightning discharge to take the shortest and most direct path to the ground, and it will readily arc over a small gap or air space or will pierce through insulating materials to the ground. If it were not for the lightning arrester, the lightning would frequently jump through the insulation of the armatures or field magnets of the car motor; and while the very small current of the lightning discharge would do no harm of itself, the arc which it would establish

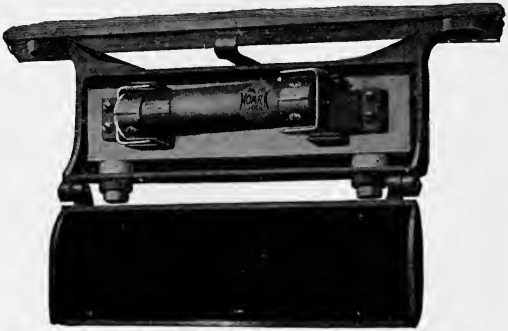
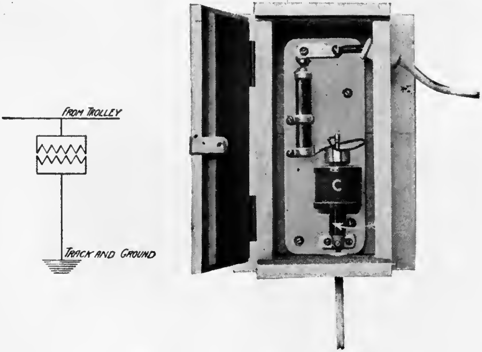


Figure 85—Closed Fuse.

in jumping to the ground would be followed by the line current from the trolley wire, which would burn out the windings immediately.

The tendency of lightning to jump to the ground by the shortest path is the principle upon which almost all lightning arresters are designed. These devices usually consist of some arrangement whereby the lightning easily can pass down the wire across to the ground by jumping between points set a small fraction

of an inch apart. Various provisions are made by different manufacturers to prevent the current from the power station from following the lightning when it is deflected to earth. Figure 86 shows a diagram of the connections of the lightning arrester. One terminal is connected to the wire from the trolley, the other to the motor truck and thence to the ground. The lightning jumps across between the points and is thus led to the earth.



Figures 86 and 87—Lightning Arrester.

Figure 87 shows a complete arrester. The two carbon points are indicated by an arrow, between which the lightning jumps on its way to earth. In order to open this special circuit after the lightning has passed, so that the current from the dynamo cannot follow by the same path that is taken by the lightning to earth, the circuit to the lightning arrester is automatically broken by an electro-magnet which pulls the two carbons apart as soon as current flows through the coil C. It will be

seen that the circuit of the lightning arrester or by-pass is constantly open except when temporarily closed while the lightning flash crosses it, and even then it is a circuit of very high resistance. It is therefore clear that even though the lightning arrester is connected to the trolley wire, yet no current from the trolley line goes through it. A kicking coil, Figure 88, is used in connection with the lightning arrester. An inductive resistance such as this coil is the only resistance that offers hindrance to the passage

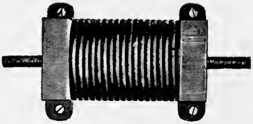


Figure 88—Kicking Coil.

Figures 89 and 90—Lightning Arresters.

of static electricity, known as lightning, and yet allows the trolley current to flow to the motors. The kicking coil, Figure 88, is put in the circuit immediately after the lightning arrester and its inductive resistance tends to drive the discharge through the arrester before it reaches the motors or other apparatus.

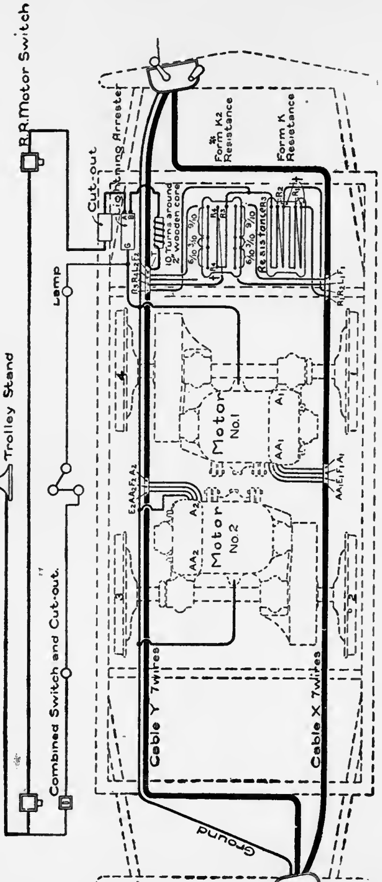


Figure 91—Diagram of Car Wiring—Two Motors.

After the line current has passed the point where the lightning arrester is connected, it flows through what is called the choke, or kicking coil, previously mentioned. The object of this is to aid in making it difficult for the lightning to flow toward the motors, owing to an inductive kick in the spiral winding, and to increase the liability of its going to ground through the lightning arrester (Figure 90).

After leaving the choke coil the current passes through a heavy wire connecting with the controllers on the platform. As will be explained in a later chapter, these controllers comprise sets of switches which are turned by the handle on top operated by the motorman. At different points in the revolution of this handle the different switches in the controller connect the motors in various ways with sets of resistance which are mounted under the car floor. After passing the controller the current is led through the resistance and to one of the brushes in the motor case. From this brush, as we have already seen in an earlier chapter, the current passes through the commutator bars and through the armature back to opposite commutator bars and out through a brush on the other side of the controller from where it entered. From this brush the current passes through all the field coils in the motor case, one after another, and then to the track by way of the axle and rails. The track, as we know, forms the return conductor carrying the current used by all the cars along the line back to the dynamo in the power station, thus completing the circuit.

Figure 91 is a diagram of the wiring in a car. The two controllers are represented at the extreme ends and the four car wheels are indicated by 1, 2, 3 and 4; between these four wheels are shown the outlines of

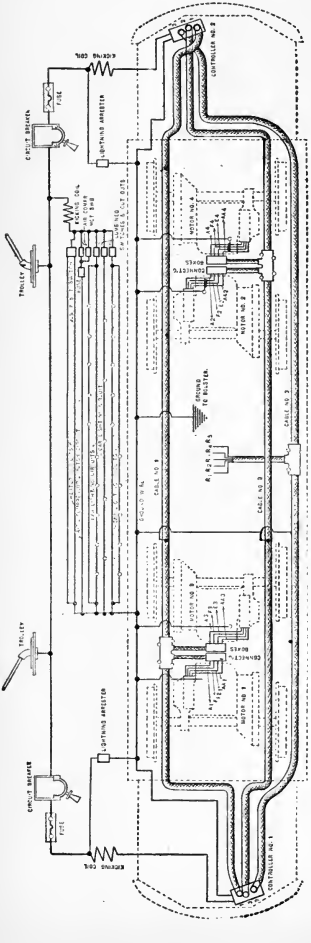


Figure 92—Diagram of Car Wiring—Four Motors.

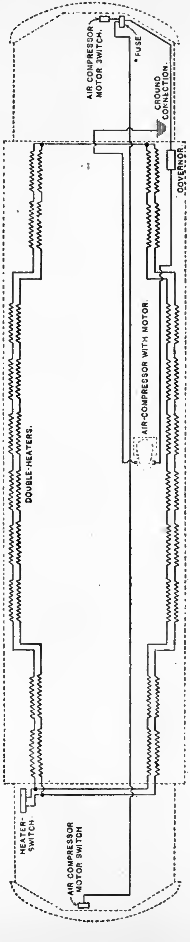


Figure 93—Heater and Air Compressor Wiring.

the two motors. The heavy tube-like connection from the controllers to the motors represents a hose which surrounds the wires going to each motor. It protects them partly from mechanical injury and partly from dampness and water thrown by wheels or rails. The resistance, hose and other devices are beneath the car floor.

Figure 92 is a diagram of the wiring of the type of double-truck car used by the Chicago City Railway. It will be noted that this car has four motors and three main groups of wires or cables which connect the motors and the resistances with the controller.

The auxiliary circuits for the lights, car heaters, bells and air-compressor motor are also shown in detail in Figures 93, 94 and 95.

This car wiring follows the practice recently adopted on a number of elevated roads of putting all wires under the car in iron pipe conduit. The motor wires between controllers are bunched into three cables. One of these cables contains the wires for motors 1 and 2, which motors are placed on one truck. The second cable contains wires for motors 3 and 4, placed on the other truck. The third cable contains wires going to the resistance grids. The compressor wiring is run in separate iron pipe conduit. The iron pipe conduit for the main cables runs along the center longitudinal sills of the car. The accompanying car wiring diagram indicates these cables and the wires leading to them, but is not intended to show the position of the conduits. Each cable conduit has all its wires of different color, so their is no confusion in repairing.

Where the taps are taken off from the cable to the motor leads, a split cast-iron junction box containing the joints is bolted on the conduit. These taps are led

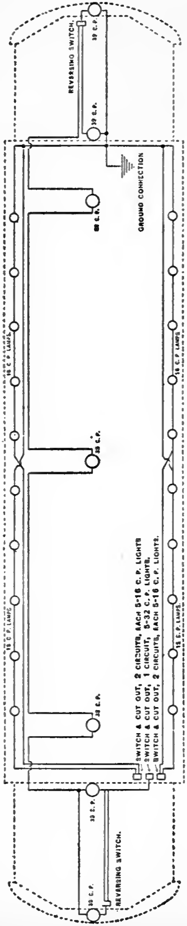


Figure 94—Lighting Circuits.

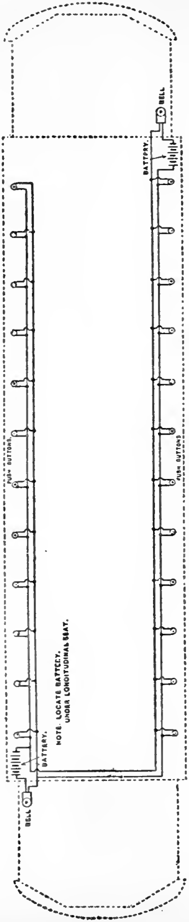


Figure 95—Push-Button Circuits.

to a connection box, which is intended to make it possible to quickly disconnect the motor leads without the inconvenience of disconnecting joints and removing joint insulation.

CHAPTER VII.

CONTROLLERS.

For controlling the speed of electric cars three general methods have been employed, two of which, however, are practically obsolete today. One method is by means of a rheostat, which was the system introduced by the Thomson-Houston Company. In this method of control the motors were connected permanently in parallel, and a rheostat was inserted in series with the two motors, containing sufficient resistance to reduce the starting pressure to less than half of the total voltage. This resistance was gradually cut out until the full voltage of the circuit passed through the motors as the car reached its maximum speed.

Another method of motor control no longer used for street cars is that in which the field coils are divided into several sections, the sections being connected in series with each other and also in series with the armature in starting. By changing in successive steps with the movement of the controller they are all thrown in parallel, and in parallel with the armature, when the car attains its maximum speed. A starting rheostat is also used with this method of control, but it is in series only on the first notch of the controller when the car is starting from rest. Both of these systems are now practically out of use.

The series-parallel method of control, which is now universally used, and which has supplanted all other methods, consists in grouping the motors on the car, together with the starting rheostat, in series and gradually, through the successive steps of the controller, changing them to parallel connection when the car attains its greatest speed. A number of controllers are described in the following pages.

The car controller is a combination of switches adapted to control the speed of the motors by admitting more or less electrical energy to the motors as the case may require. These changes of connections may be made by a number of independent and separate switches, but if this were done too many switches would be required, and they would be slow and awkward to operate, and would occupy too much room. Experience has shown that a circular contact drum is quick acting and a suitable device on which a great many changes of connections can be made simply and easily. The purpose of the controller is threefold:

1. To connect the motors into the circuit so that current can flow through them.

2. To regulate the amount of current flowing to the motors so as to make a gradual start and control the speed of the car.

3. To govern the direction of travel of the car.

The electrical pressure on the trolley line (technically called voltage) is kept practically constant at the power station. Therefore, if the current at full pressure were admitted suddenly to the motors, and no means provided to allow it to rise gradually, we would have to expect a similar abrupt and sudden start by the motors from a state of rest. Admitting the full current would strain the electrical parts, and similarly the

sudden start from rest to high speed would tax the bearings and other mechanical supports and gears, to say nothing of the discomfort which the passengers would experience by the jerk with which the motors would start the car.

Resistance.—To control the amount of current it is necessary to consume a portion of the pressure

Figure 96—Car Resistance.

under which the current flows by interposing some material which offers a resistance to the flow of the current until the motor has been gradually increased to its normal speed. All the switches or contacts for such grading or varying of resistance are mounted on the drum of the controller (described later), while the resistance itself is generally fixed at a convenient place below the car body. Substances that offer resistance to the flow of current are iron wire, iron strips or plates, German silver, etc. For electric railway pur-

poses iron plates or bands are generally used, which are supported in an iron frame, the turns or convolutions being insulated from each other and the fireproof frame by mica. The complete device is termed a resistance, though some call it a rheostat or a diverter.

Assume, for the sake of illustration, that the total length of the iron resistance band is 40 feet, in divisions of 10 feet each, these divisions being connected to the controller terminals by means of wires mentioned in the previous chapter. Now, if this controller were placed on the first notch the whole 40 feet of iron band would be in circuit with the motor, and the pressure that could reach the motor reduced just the amount that would be lost in the 40 feet of iron band. By turning the controller to the second notch, 10 feet of this iron band would be cut out, so that but 30 feet would be in circuit. The pressure that could reach the motor in this case would, of course, be greater and its speed would increase. Turning the controller to the third notch, but 20 feet, to the fourth notch, but 10 feet, of the resistance would be left in the circuit, and at the fifth position the resistance would be out entirely, causing an increase of speed with every reduction in resistance and a maximum speed when all resistance was cut out. A resistance or diverter is shown in Figure 96. Its terminals, by which, as just

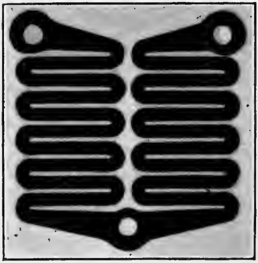


Figure 97—Resistance Grid.

explained, the resistance is subdivided (Figure 97), are led to the controller.

Motor Circuits.—In order to understand clearly all the different changes and conditions that take place by means of the controllers, it is desirable to make the reader acquainted first with the different modes of circuit connection and their names, and then immediately apply them to standard types of controllers. After the preliminary explanation some types in gen-

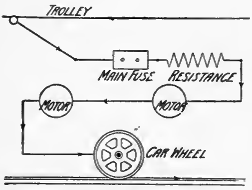


Figure 98.

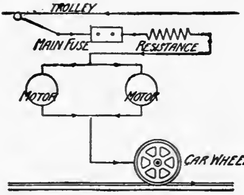


Figure 99.

eral use will be described in detail, and the rest will be understood after a simple statement of the successive steps and changes as they take place.

If several parts or conductors are grouped so that the total current flows in succession through all parts, they are said to be grouped in "series," as for instance in Figure 98. The trolley, the main fuse and the resistance carry the total current that goes to the motors, and they are said, or each one of them is said, to be in series with the motors. The motors are also in series with each other, as the current flows first through one, then through the other. It will be clear that if for any cause the main fuse should melt, there would be a

separation between the trolley pole and the resistance and the current could not flow.

Another mode of connection is called "parallel" or "multiple" connection. This is shown in Figure 99. The full current supplied to a car goes down the trolley pole, and if the motors are grouped, as shown in this figure, the current will divide and half of it will go to one motor and the other half to the other motor. Where the circuits of the motors are connected again the two currents join and flow on as one through the car wheel and rail. The two motors are connected in parallel or multiple with each other. However, this

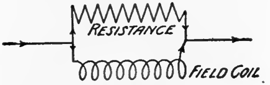


Figure 100.

connection is not restricted to motors only. Any two or more conductors placed in such a relation that the original current will split up into several paths and join at a place farther on are said to be connected in parallel, or shunt, or in multiple. For instance, resistance may be in parallel with or in shunt circuit to the field coils of a motor (Figure 100), a connection which is made in some modern controllers.

A third way of connecting parts is made by a combination of the two ways just described. Some of the devices with relation to others are in series with one another and in parallel with others, and such grouping is called series-parallel or parallel-series connection. Figure 101 explains this clearly. It represents a condition of grouping of four motors, 1, 2, 3 and 4.

Evidently the current splits at A, divides into two currents, one of which flows through motors 1 and 2, the other through motors 3 and 4. The volume of current that goes through motor 2 must therefore be the same as that going through motor 1, and the relation is similar between motors 3 and 4. At point B the currents join and the total current flows to the car axle and car wheel C. In this combination motors 1 and 2 are in series, and so are motors 3 and 4, but the 1 and 2 combined are in parallel connection with 3 and

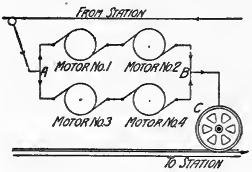


Figure 101.

4 combined, and the whole combination is called series-parallel.

Series-Parallel Control.—Since 1893 an improved form of controller known as the "series-parallel" controller, has come into general use for single-car operation. The power required when first starting a car with the motors in series is only one-fourth what it would be with the same motors in parallel. Consequently, in the modern controller the motors are in series on the first few points of the controller as in Figure 98, and after about half speed has been reached they are connected in parallel as in Figure 99. Hence the name, series-parallel controller.

The difference between the old method of control and the new is that formerly, to reduce the pressure

at the motor terminals at the start, a great resistance was inserted to consume a part of the pressure and the energy thus spent in the resistance was wasted. In the new way the two motors are grouped in series first, so that the current must flow through one motor before it gets to the next (Figure 98), and therefore but one-half the pressure reaches each motor. The energy passing through the first motor (which causes the reduction in pressure for the other) is not wasted, as it is doing useful work in turning the armature and increasing the turning force necessary for starting the car.

Practically all new cylindrical controllers in use today may be divided into four classes, as follows:

Type B controllers, which may be either of the series-parallel or rheostatic type, but which always include the necessary contacts and connections for operating electric brakes.

Type K controllers of the series-parallel type are almost universally used. In these controllers one of the features is the shunting or short circuiting of one of the motors when changing from the series to the parallel connection.

Type L controllers are also of the series-parallel type, but differ from type K controllers in that the circuit is completely opened when the change from series to parallel is made.

One of the most important features of these types of controllers is the magnetic blow-out by means of which any arc forming between the controller terminals is blown out. Other important features are the cut-out switches and the interlocks. The cut-out switches are arranged so that either motor on the two-motor equipments, or either pair of motors on the four-

motor equipments, may be cut out without impairing the operation of the remaining motors. The interlocks prevent, as far as possible, the abuse of the controller, as they make movement of any of the handles impossible unless the remaining handles are in such a position that no trouble can result. These controllers are built with hinge clamps, permitting the cover to swing open from either side, or to be completely removed. The parts of all these controllers are interchangeable, permitting ease of repair and renewal.

In the following descriptions of controllers there are included controllers which are no longer manufactured, but many of these older controllers are still to be found on different roads where the old equipments have not yet been discarded, and it was therefore deemed advisable to include descriptions of the old as well as the modern controllers.

The series-parallel controllers manufactured at the present time are as follows: K-2, capacity two 40-hp. motors, 5 series and 4 parallel points; K-4, capacity four 30-hp. motors, 5 series and 4 parallel points; K-6, two 80-hp. or four 40-hp. motors, 6 series and 5 parallel points; K-10, two 40-hp. motors, 5 series, 4 parallel points; K-11, two 60-hp. motors, 5 series and 4 parallel points; K-12, four 30-hp. motors, 5 series and 4 parallel points; K-13, two 125-hp. motors, 7 series, 6 parallel points; K-14, four 60-hp. motors, 7 series, 6 parallel points; K-27, two 60-hp. motors, 4 series, 4 parallel points; K-29, four 40-hp. motors, 6 series and 5 parallel points; K-31, four 30-hp. motors, 4 series and 4 parallel points; K-32, two 40-hp. motors, 4 series and 4 parallel points; L-2, two 175-hp. motors, 4 series and 4 parallel points; L-3, four 150-hp. motors, 8 series and 7 parallel points; L-4, four 100-hp. motors, 4 series, 4 parallel

points; L-7, four 200-hp. motors, 9 series and 6 parallel points.

The electrical brake controllers are designated by the letter B, and are as follows:

B-3, capacity two 40-hp. motors, 4 series, 5 parallel and 6 brake points; B-7, two 100-hp. motors, 6 series, 5 parallel and 6 brake points; B-8, four 60-hp. motors, 6 series, 5 parallel and 7 brake points; B-13, two 40-hp. motors, 5 series, 4 parallel and 7 brake points; B-18, two 40-hp. motors, 4 series, 4 parallel and 6 brake points; B-19, four 40-hp. motors, 5 series, 4 parallel, 7 brake points; B-23, two 60-hp. motors, 5 series, 4 parallel and 7 brake points; B-29, two 60-hp. motors, 5 series, 4 parallel and 7 brake points. The latter is similar to B-23, but has a separate brake handle.

In Figure 102 is shown one of the type K controllers of the General Electric Company. There are many types of K control adapted for motors of different ratings, but the principle of operation of all is similar, so one description will suffice. On the top of the controller are visible two handles. The one located near the center of the controller top, called the controller handle, is attached to a spindle which passes through the whole length of the controller. On this spindle is mounted a cylinder by means of which the current is turned into the motors. The second handle, called the reversing handle, is located at the right-hand side and its purpose is to control the direction of the car. If this handle is pushed forward as far as it will go, the car will go ahead when the controller handle is turned to close the circuit. The car will run backward when the reversing handle has been pulled to the other extreme position and the controller handle is operated as before. What takes place is this:

The reversing lever operates a small drum inside of the controller which is provided with contacts. This handle has three positions. The working of this handle forward or backward changes the connections of the

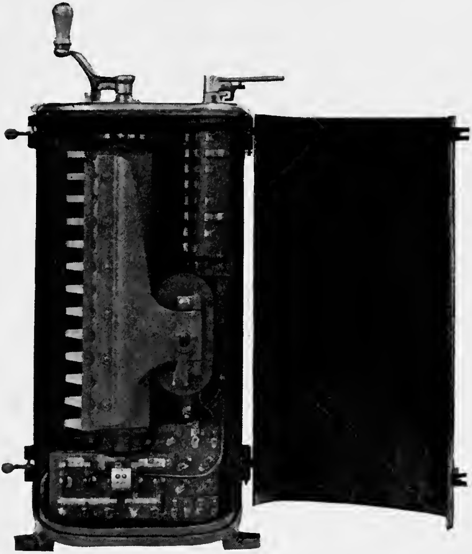


Figure 102—K-2 Controller.

motor armatures so that the current flows through them in one direction when the car is to go ahead, and in the opposite direction when the car is to go backward, as explained in the previous chapter. When the reverse handle stands at the intermediate position

between forward and reverse, the current is shut off from the motor at that controller and the reversing handle can be removed only when it is at this intermediate position. An interlocking arrangement prevents any movement of the reversing handle except when the large or power cylinder is at the "off" position. This same locking device prevents any movement of the power cylinder except when the reversing handle is fully thrown into proper position and standing at either "forward" or "backward."

The reversing cylinder, therefore, controls the direction in which the car moves. The propelling of the car and its speed are controlled by the controller handle, with which the motorman has far more to do than with the one just described. We will, therefore, go fully into the details of changes that take place when the controller handle is shifted from one point to another.

On the top of the controller there are a number of points or dashes, and on the spindle is fastened a finger or index which points to these raised marks as the handle is moved around to admit current to the motors. The high controlling lever on the top (Figure 102) turns the central shaft on which are mounted the contact pieces or sections, which establish connections with the stationary terminals located to the left. The wires to the left connect with the terminal board in the controller, to which are also attached the wires going to the motors and to the second controller and resistance boxes.

When the car is standing ready to start, the finger points to the position marked "off." To start the car, the handle is moved around in the direction of the hands of a watch to the first point. This connects the motors and resistance to the circuit so that the current

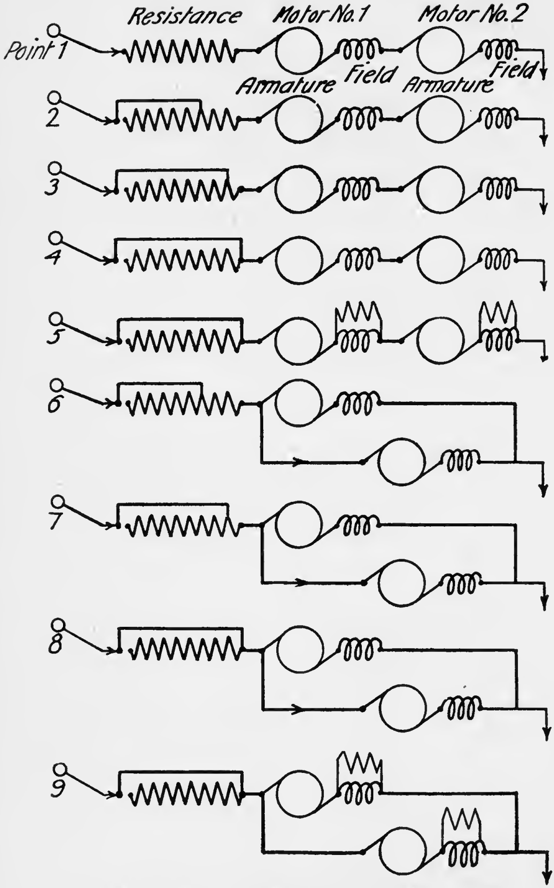


Figure 103—Motor Connections on Successive Points.

flows first through the iron plates of the resistance, then through one of the motors, then through the other motor, and finally to the ground through the car truck, wheels and rails. The motors are in this case what is technically known as connected in "series." This is represented in the diagram showing the connections on the first point in Figure 103. The connections made on all the following points of this controller are also shown in the same figure and should be studied while reading this explanation. On the second point it will be seen that the connections remain the same as on the first, except that two-thirds of the resistance has been cut out of the circuit, so that more current may reach the motors. On the third point, eleven-twelfths of the resistance is cut out of the circuit, and on the fourth point, all the resistance is out, so that the current flows only through the two motors in series.

All resistance is now cut out and no power is being wasted, as the current is doing only useful work in the motors. We can therefore keep the controller on this point for any length of time with economy, only the car will run a little less than half its maximum speed. To increase the speed still more, we move the controller to the fifth point. In doing this, connections are made so that part of the current is shunted through a resistance around the field coils of the motor; that is, instead of having all the current that flows through the armatures flow also through the fields, a part of it is made to take a by-pass or shunt around the fields. This has the effect of increasing the speed of the motors, and they will on this point run at half the full speed. In moving the controller to the sixth point, an important change is made in the connections of the motors.

As said before, when the controller is on the fourth and fifth points, the motors are in series with each other, the current flowing first through one and then through the other. Consequently each motor gets only one-half the pressure existing between the trolley wire and ground. That is to say, by the time the current has passed through the first motor, half of the pressure has been used, leaving only the remaining half to run the other motor. To increase the speed we must now connect the motors so that they both will get the full pressure from the trolley line. This cannot be done abruptly. Some resistance must be introduced into the circuit at the time this change is made to prevent the car from jerking, just as it would have acted on the first point had some resistance not been interposed when first starting. Therefore, on the sixth point, the motors are connected so that the current divides and half flows through each motor. They are then what is technically called connected in "parallel." They both get the full pressure, except that some resistance is put in the circuit before the current gets to the motors. A part of this resistance is cut out on the seventh point. On the eighth point all of the resistance is out and the motors are connected so that they both get the full pressure and run at nearly full speed. On the ninth point part of the current is shunted around the field coils as on the fifth point, and the motors run at their highest speed.

At each point there is provided a notch on a wheel or ratchet, mounted on the controller spindle inside the controller case, which prevents the handle from stopping between points when it is turned. At the lower end of the controller are located the motor cut-out switches, which enable one to operate a car with a

single motor should the other one have become defective. The operator will find an instruction card in each controller, stating plainly how to throw the switches to cut out the defective motor. It will be

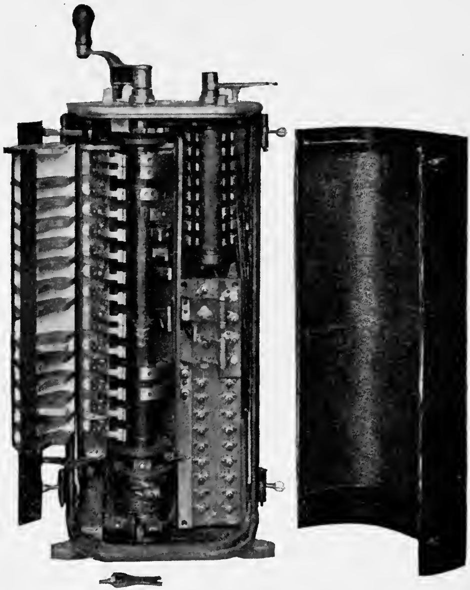


Figure 104—K-6 Controller.

noticed that the cards do not read alike on the two controllers of the same car. This is due to the difference in connection. Should it at any time become necessary to cut out a motor, look for the instruction

card in the controller stand. To operate with a single motor, the car will start on point 1 and reach its full speed on point 5. A stop is placed on the controller spindle, with which a pin engages, preventing movement of the controller cylinder beyond the fifth point. This is effected by either of these cut-out switches, which, in being raised, operate the pin.

The K-4 controller is used in connection with larger cars, where four motors instead of two are mounted on the trucks. Its action is like the K-2 controller, with the difference that instead of having two motors first in series and later in parallel, there are in the K-4 control two identical sets of motors with two motors per set. The two motors of each set are permanently grouped in parallel, and one pair is first placed in series with the other pair or set, and finally the two series are connected in parallel.

The K-6 controller, which is designed for two 80-hp. motors or four 40-hp. motors, is shown in Figure 104.

The K-10 controller is designed for two 40-hp. motors. It is a controller with nine notches. On the first four notches the motors are in series and the resistance in circuit. On the fifth notch the motors are in series with the resistance all cut out. On the sixth, seventh and eighth, the motors are in parallel and the resistance in circuit. The ninth is for full speed, motors in multiple. The K-10 controller is shown in Figure 105. Field shunts are not used with this controller.

The K-11 controller is the same as the K-10, except it is designed for heavier currents and larger motors.

The K-12 controller is like the K-11, except that it is made to operate four motors in two sets, the same as the K-4.

The K-13 is designed for two 125-hp. motors. It is a 13-notch controller. The motors are in series up to and on the seventh point. From the eighth to the

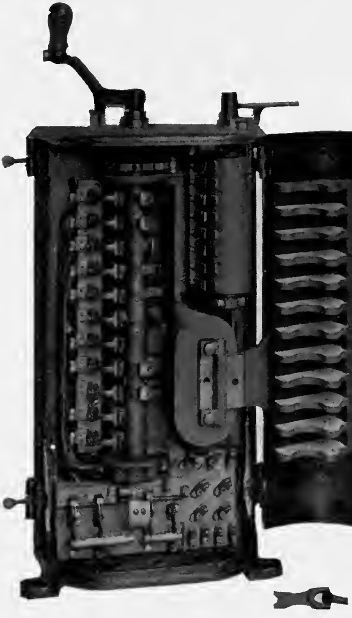


Figure 105—K-10 Controller.

thirteenth they are in multiple. The preferred running notches are the seventh and thirteenth. No field shunts are used.

The K-14 is for four 60-hp. motors, and is like the

K-13, except that it handles four motors in two groups, as does the K-4.

The K-27 controller is similar to the K-11, but is arranged for operation on a metallic circuit, having contacts for opening both sides of the circuit.

The K-29 controller is similar to the K-6, but has contacts for opening both sides of the circuit.

The K-31 controller is similar to the K-27, but has reverse switch arranged for four motors.

The K-32 controller is also similar to the K-27, but is of smaller capacity.

The L-2 controller is used for two 175-hp. motors, and the L-4 for four 100-hp. motors. They have four points in series and four in multiple. The handle is operated contrary to the hands of a watch, or in the opposite direction from most controllers. The first half-revolution moves the controller through the series points and brings them into full series. To throw them into multiple the movement of the handle of the controller is continued on around to the original off position, and when the handle begins to pass over what were the series notches on the first revolution, the motors are thrown in multiple, so that when the handle has completed a revolution and a half the motors are connected for full speed in multiple. The current is always off when the handle is at the left, and always on when it is at the right. A brass dial on top of the controller indicates whether the motors are in series or multiple.

The L-3 controller for four 150-hp. motors has 15 points, eight series and seven parallel. This controller is shown in Figure 106.

The L-7 controller for four 200-hp. motors has 15 points, nine series and six parallel.

The controllers for use with electric brakes are known as the B type. The action of the electric brake and the way to operate it are described later in the chapter on brakes. Some of these controllers have a double set of points or notches. Moving the handle

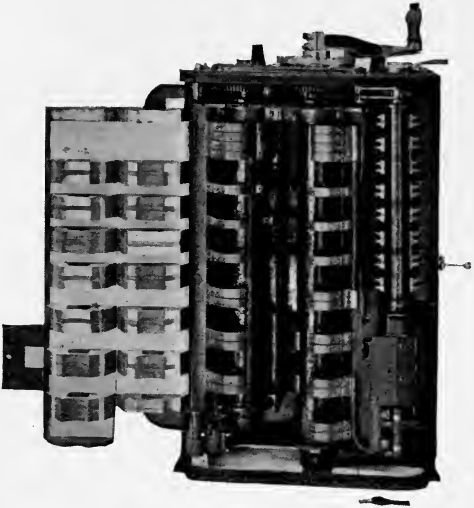


Figure 106—L-3 Controller.

in the usual way from off position starts the car just as on other controllers. Moving the handle the other way from off position applies the electric brake, if the car is running. The capacities of the B controllers at present manufactured and the number of controlling points on each have already been shown in this chapter.

The B-8 controller has separate handles for power and brake, as is also the case with the B-7, B-19 and the B-29.

The B-23 controller has but one power and brake handle. The B-3, B-13 (shown in Figure 107) and B-18 also have only one handle, which is operated in one

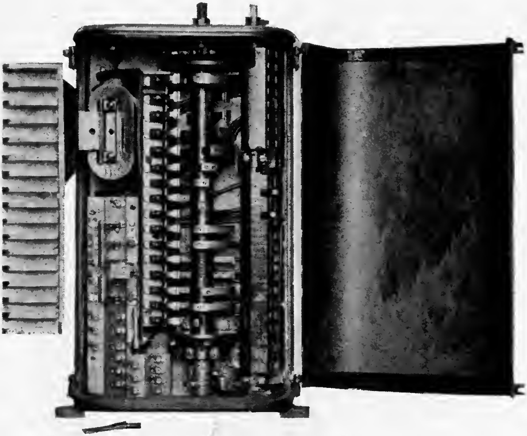


Figure 107—B-13 Controller.

direction for the power and in the other direction for the brake, as just described. Of the B controllers the B-13 is most generally used and its braking connections are such as to render the skidding of the wheels practically impossible.

Controller with Contactors.—The increased power and higher voltages now being used on many electric

railways have imposed new requirements in the design of control apparatus for railway motors, mainly owing to the more destructive character of the arcing in case of a grounded motor or derangement of other appa-

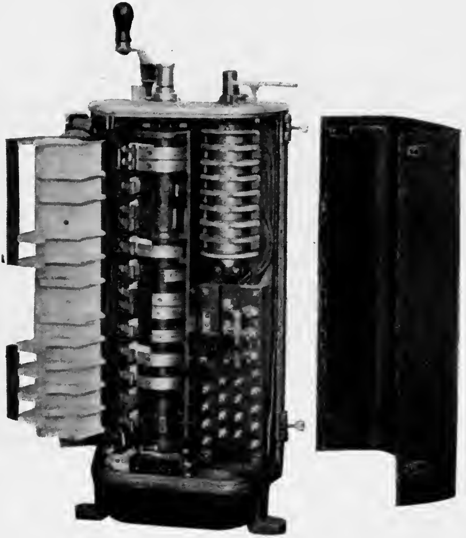


Figure 108—K-28-J Controller.

ratus. To meet these requirements there has been developed an auxiliary equipment adapted for use with practically all standard cylinder controllers, consisting essentially of two standard Sprague-General Electric Type M control contactors (see Chapter VIII) con-

nected in the main trolley circuit, and additional contacts in the controllers for opening and closing the contactors when the controller is turned off and on, respectively.

By this means all heavy arcing is eliminated from the controller as the power circuit is opened by the contactors under the car, and consequently the wear and tear on the controller fingers and contact surfaces is diminished, repairs minimized, and the possibility of burnt-out controllers practically prevented. A controller Type K-28-J fitted with the contactor attachments is shown in Figure 108.

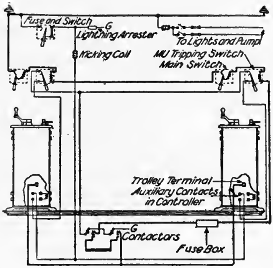


Figure 109.

In addition, this equipment includes overload devices known as MU tripping switches which interrupt the energizing circuit of the contactor coils in case of an overload, causing the contactors to open the main circuit. These tripping switches perform the functions of circuit-breakers and may be substituted for them.

The control connections are shown in the wiring diagram (Figure 109). The auxiliary controller attachments can be fitted to the following controllers: K-6, K-10, K-11, K-12, K-14, K-28 and L-4, with but slight change. The automatic MU tripping switch replaces the usual platform circuit-breaker and is smaller

and more compact. This combination control is designed for a single-car equipment and must not be confused with the standard multiple-unit control for operating several motor cars together, which is described in Chapter VIII.

CHAPTER VIII.

MULTIPLE-UNIT CONTROL.

On some electric railways where the traffic is heavy it becomes necessary to run trains of several cars, some or all of which are motor cars. It also becomes necessary at times to divide these trains into smaller ones or to add more cars as the traffic fluctuates, and as it is obviously unpractical to have more than one motorman to drive a train, means must be provided so that each motor car of the train may be controlled from the head end by one man. This method of control is generally known as the multiple-unit system of control.

The multiple-unit control system is designed to operate a train of two or more cars from a single master controller or from any car in the train. The train consists of several cars, each propelled independently by its own motors and controlled as one car. Each motor car is provided with two master controllers, one at each end of the car in the motorman's compartment. All master controllers are connected to the train cable, which runs the entire length of each car and is joined between cars by the train cable-jumper. The current received through the master controller and train cable operates

electrically controlled switches, known as contactors, on each car, and establishes the motor control on their respective cars. The motor control is local with each car and can be governed by any master controller on the train. The multiple-unit system allows the greatest flexibility in the operation of cars, for one car may be run alone or any number of cars may be coupled together, each car being driven by its own motors as an independent unit.

There are two systems of multiple control in use, that of the General Electric Company, known as the type M control, which is electrically operated, and the Westinghouse multiple-control system, which is operated by means of compressed air, and known as electropneumatic control. Each may be arranged for alternating-current service as well as direct.

Type M Control.—In the type M control the series-parallel motor controller as described in the previous chapter is replaced by a number of electrically operated switches, called contactors, which are placed under each motor car. There is also a separate electrically operated reversing switch called the reverser. These contactors and the reverser fulfill the same functions as the controllers on a single car, making the same combination of the motors and starting resistances. Instead, however, of being directly operated by the motorman they are operated through a small controller, called the master controller, to which all the contactors and reversers on the train are attached by means of a control circuit cable. This cable runs the entire length of the train and is connected from car to car by means of suitable couplers, and when trail cars are placed between motor cars they also are provided with cables. The platforms of each motor

car and, if desired, those of each trail car are equipped with master controllers (Figure 110).

The master controller, type C-38-D, shown in Figure 111, although smaller than the ordinary controller, is similar in appearance and method of operation. It has separate power and reverse handles and contains a magnetic blowout similar to that of the ordinary controller. All the current for the operation of the contactors is taken from the line and passes directly through whichever master controller happens to be in use; and the handle of the master controller is generally arranged so that if the motorman removes his hand from it the control circuit will be broken and the contactors opened, shutting off all current from the motors. The reverse handle can only be removed when the power handle is in the off position and the power handle is mechanically locked when the reverse handle is removed.

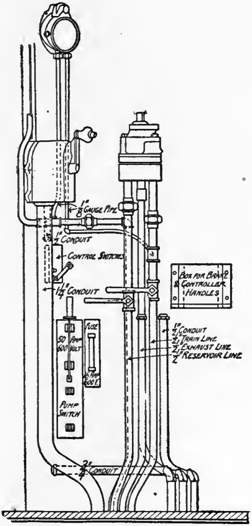


Figure 110
Controller and Switches in Cab.

The contactors (Figures 112 and 113) each consist of a movable arm with a removable copper contact at one end, making contact with a similar fixed contact piece, and a coil which actuates the arm when

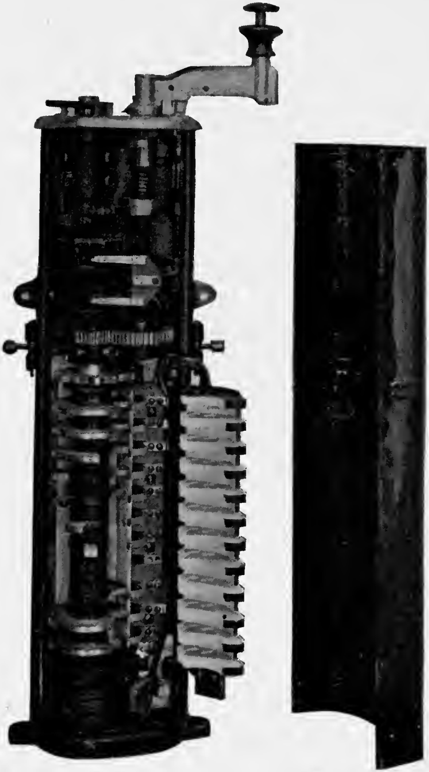


Figure 111—C-38-D Controller.

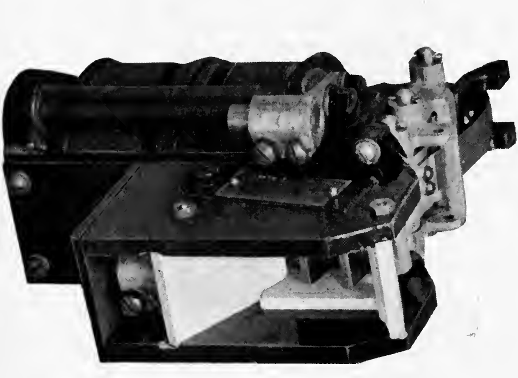


Figure 112—Direct-Current Contactor.

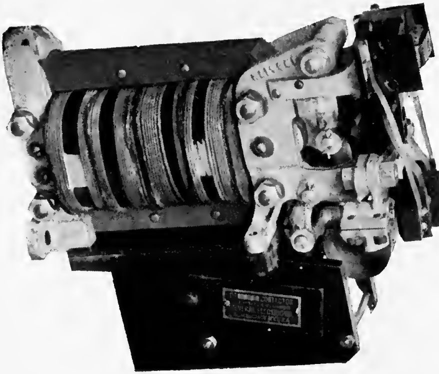


Figure 113—Alternating-Current Contactor.

supplied with current from the master controller. The contactor is closed only when the current of the control circuit passes through its coil, and gravity, assisted by the spring action of the contact piece, causes the arm to drop and the circuit to open when the control circuit is broken. The contactor also has a powerful magnetic blow-out. The reverser is somewhat similar to the ordinary reversing switch with the addition of electro-magnets for turning it either to the forward or reverse positions. Its operating coils are similar to those of the contactors. A cut-out switch is also provided, by means of which all of the control operating circuits on any car may be cut out.

It is evident from the foregoing explanation that there are two principal circuits (Figure 114 at end of book) on a car with the type M control. First, the control circuit which passes from the line to the contact shoe on the car, thence to the master controller, thence through the various operating coils of the contactors and reverses and thence to the ground return; second, the motor circuit, which from the contact shoe passes through the various contactors, thence to the motor fields and armatures and thence to the ground return. All of the contactors under each car taken together constitute a series-parallel controller, and the different combinations are indicated by the position of the master controller handle. The diagram (Figure 116 at end of book) shows the complete connections of the C-36-B controller and its auxiliary apparatus for a four-motor equipment. The running points on this controller are 5 and 10, 5 being the series connection of the motors and 10 the parallel connection. The intermediate points are resistance points. As this system of control is made up of separate electrically operated

switches, these may be located in any available position and are generally placed under the car floor.

Electro-Pneumatic Control.—The Westinghouse multiple unit-switch train control system employs compressed air to operate the controlling apparatus, electro-magnetic valves for controlling the admission of air to the various cylinders and a low-voltage control circuit for actuating the electro-magnets. The essential parts of this system consist of a series-parallel controller on which is mounted an operating head consisting of a number of air cylinders, a master control switch and two sets of storage batteries. With some changes the system is adapted for either alternating or direct current operation.

Figure 115—Unit Switch.

In the unit-switch control system the main drum of the hand controller is replaced by a group of 10 or 12 (according to the size of the equipment) independent or "unit" switches, each provided with a strong magnetic blow-out and normally held open by a powerful spring. Each switch (Figure 115) is closed when desired by a suitable pneumatic cylinder, using compressed air from the brake system. This combination of switches is called a "switch group." The reverse drum of the platform controller is replaced by a similar drum, except that it is more liberal in capacity, built in a sep-

arate case and moved to the forward or reverse position by one or the other of two cylinders having a common piston rod. This device is called a "reverser" (Figure 117). The overhead circuit-breaker is replaced by a "line switch," which is essentially the same as one of the switches of the switch group, except that it is placed in a case by itself and is provided with an automatic trip, which causes it to open in case of an overload or short-circuit. These three pieces of

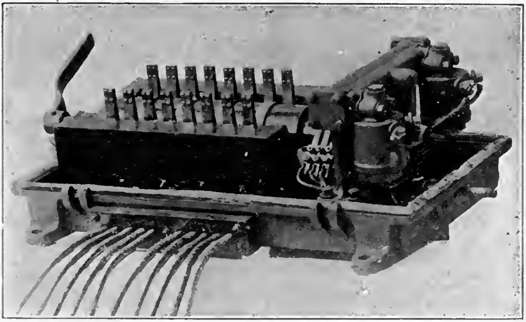


Figure 117—Reverser.

apparatus effect the various necessary connections between motors, resistance and trolley.

Forming an essential part of the pneumatic cylinder for operating the switch group, line switch and reverser is a magnet valve which governs the admission or escape of air to or from that cylinder. These magnet valves are operated by means of a small storage battery, and their opening or closing is regulated by means of a "master controller" to which their circuits are led. The switch group, reverser and line switch

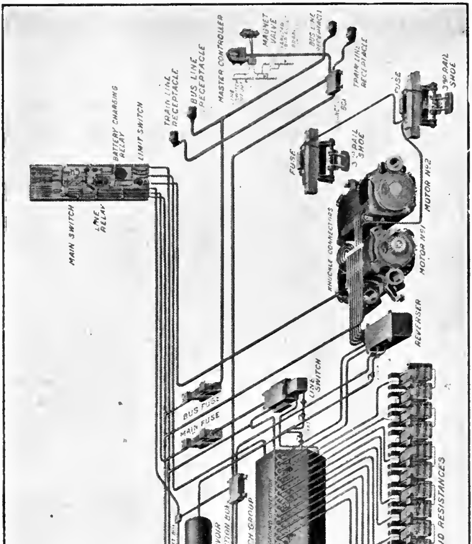


Figure 118—Westinghouse Electro-Pneumatic Control System.

thus may be located in any convenient position, while nothing but the master controller need be located on the platform, and only the small low-voltage battery circuits be carried to it.

For train operation the circuits from the battery and magnets are carried to "train line receptacles" at each end of the car, as well as to the master controllers, and when two cars are coupled together the corresponding receptacles on each car are then connected by a multipoint "jumper," so that the circuits are continued from car to car. When several cars are connected in this way the movement of a single master controller closes simultaneously the corresponding magnet circuits on all of the cars and thus operates also the corresponding main circuit switches.

Connected to the piston rods which move the various switches are a number of small contact switches which open or close auxiliary circuits between stationary fingers arranged to press on them. These auxiliary contacts are called "interlocks," and the circuits which operate the magnet valves of each of the various switches are carried through the interlocks of other switches in such a way that the switches cannot be closed except in the proper order.

The unit-switch control system (Figure 118), however, does not consist merely in replacing the ordinary controller with a set of pneumatic switches, which may be closed properly or improperly entirely at the discretion of the motorman, but the action of the switches is regulated by means of a "limit switch," so as to give a uniform current through the motors while operating on the resistance steps; thus securing a smooth and even acceleration of the car and protecting the equipment from overload. This limit switch consists

of a coil, placed in series with the motor circuits, which lifts an armature whenever the current exceeds a predetermined amount.

The circuits for closing the various switches of the switch group are so arranged that it is not necessary to move the master controller step by step to cause the closing of the different switches, but, by placing the master controller in a single definite position and holding it there, the circuits to the first switches are closed. The closing of these switches then automatically closes the next ones, etc., by means of the interlocks. The circuit from the battery which supplies power for this automatic operation is led through the secondary contacts of the limit switch, so that as long as the current through the motors does not exceed the desired value, the different switches will close one after the other almost instantaneously. Should the current through the motors at any time exceed the desired amount, however, the armature of the limit switch will instantly rise and thus prevent the closing of any more switches until the current has fallen to the desired value.

The regulation of the current during starting is thus taken entirely out of the hands of the motorman, who simply advances the handle of the master controller to the last notch and holds it there; the closing of the switches is then governed automatically by the limit switch. In order to provide for the handling of the car under special conditions, the apparatus is so arranged that the motorman may readily notch up more slowly than would be done by the limit switch, or may stop at any notch; also, by going to some extra trouble he can short-circuit the limit switch and notch up entirely independent of the current.

As ordinarily built, the master controller (Figure

119) for use with the unit-switch control system contains three notches for forward running and three for reverse. If the handle is moved to the first notch a slow-speed resistance point is obtained which is used principally in shifting cars. This first notch hence is called the "switching" position. If the handle is moved to the second notch, either with or without pausing on the first one, the switches close one after the other until the motors are connected in series. The second notch is therefore called the "series" position, and is, of course, a running point. If the handle is moved to the third notch, either at once or after pausing on one or both of the first two notches, additional switches will then close in sequence until the motors are connected, in full multiple. The third notch is called the "parallel" position.

Figure 119
Master Controller.

An interesting detail to learn in connection with this system of control is the method of charging the small storage batteries used for operating the magnet valves. Two batteries are carried on a car, and these are connected to the air-pump motor circuit, as shown in Figure 118. The two double-throw switches are always thrown either both up or both down, so that one battery is connected to the control circuit while the other is being charged. Whenever the pump is running the battery which is being charged is connected by the "battery-charging relay" to the circuit of the pump motor. The resistance in series with the pump

motor is so adjusted, in connection with the relative amount of time that the pump is running and the control circuits are closed, that the battery will receive on the one hand sufficient current to charge it properly, without, on the other hand, receiving enough current to make it boil or gas. When this adjustment once has been made, the batteries will require little attention other than the reversal of the two switches once each day.

Another detail of the equipment is the air-storage system. A separate "control reservoir" is piped to the air-brake system, as shown in Figure 118, in connection with a "governor" or check valve and a three-way valve. Ordinarily the three-way valve is turned so that the air is drawn directly from the brake system, but in case of accident to the compressor or main reservoir the three-way valve may be turned through a right angle and the reserve supply of air in the control reservoir thus be made available to return the car to the car house.

In providing for the control of the different sizes of motors most commonly used, two sizes of switch groups are employed. This method of control, with slight modification, is adaptable to either direct or alternating current, or both, as shown in Figure 120 at end of book.

CHAPTER IX.

OPERATION OF CONTROLLERS.

The value of an employe depends upon the economy with which he can operate his car—economy in the way of preventing costly accidents, economy in power and economy in wear and tear of the cars, trucks and motors he runs. What has been said before has been intended to prepare the reader for this chapter, which deals directly with an employe's actual duties. It does not require any special knowledge to be able to get a car over the road. To operate it in the best possible manner is quite another matter. It is the main object of this book to tell electric railway employes how to make themselves valuable men; how to operate a car with greatest economy.

Let the operation of controllers first be considered, beginning with the series-parallel controllers which are in common use today. The operation of all the controllers is very simple. They all have reverse levers at the right of the stand or on the top, and the controlling handle on nearly all is moved around in the direction of the hands of a watch to turn on the current, and in the opposite direction to turn off the current. Before trying to start a car, first be sure that the brakes are off, that the controller handle at the other end of

the car is on the "off" position and the canopy switches are closed. Then move the controller handle to the first notch. The car will start if all is right. After the car is well under way on the first notch, move to the second, and so on to the last. In moving from one notch to another do not stop the handle between notches, but give it a push strong enough so that it will go to the next notch. A timid or inexperienced motorman is apt to turn the handle slowly, but this is bad practice.

Always wait long enough on each notch for the car to gain speed before passing to the next notch. If this is not done, much more current than necessary may be used to move the car. The wheels may slip, the motors will be strained and overheated, and there will be a great drain on the power station generators, and wear on machinery. When the notch is reached where the motors are in series and there is no rheostat resistance in the circuit, special care should be taken to let them gain speed and run up to nearly the maximum speed they can attain in this position before passing to the higher notches where the motors are in parallel. When the motors are thrown in parallel too soon in starting, a waste of power takes place. This notch on which the motors are in series with no rheostat resistance in the circuit is indicated by a long mark on the top of the controller. It is on this series point that the motors exert the greatest pull with the least current, and it should preferably be used when there is heavy pulling to be done or steep grades to be climbed.

On looking at the points marked on the controller tops it will be seen that some of them are marked with longer or heavier marks than the others. Those points with long marks are called "running" points, because on them the motors may be operated for any length

of time without overheating or wasting current in the rheostats. Among these running points there are some to be preferred because on them the whole energy taken into the motors is used to propel the car. These preferred points are those positions on which no rheostat resistance or diverter is left in circuit with the motors.

On the K-10 controller the preferred running point is the fifth, at which the motors are in series and resistance all cut out. This should be used for slow running. It gives half full speed. The ninth point is the high-speed point, and is for use only on a level. Use of the fifth or ninth points on grades is very wasteful of current and hard on the motors, and little is gained by it in the way of speed.

In shutting off current the controller handle should be brought rapidly to the off position from whatever point it may happen to be on, without stopping at any point. To run the car backward when it is standing, pull the reverse lever back and turn on the current as when running forward. Sometimes it is necessary to reverse when the car is running ahead, in order to avoid running into something. To do this, throw the controller handle to "off" and pull back the reverse handle. Then move the controller to the first notch. The car will stop with a jerk and begin to go backward. This way should be resorted to only when there is danger, and even then the car speed should be slow, because it is not a sure remedy. The fuse may blow and thereby suddenly shut off the power on account of the abnormally heavy current flowing. There is also a possibility that one or the other motor may be permanently disabled.

There is one way, however, in which a violent stop

can be made with a series-parallel controller, even when the power is cut off and the brakes fail. It is done by reversing if the car is moving ahead, or throwing the reverse level "ahead" if the car is backing, and putting the controller handle on the highest point of the controller. In this case the motors act as dynamos, generating current. This method may be used in emergencies when the brakes are not sufficient and the trolley has come off or the fuse has blown and the car is going down an incline.

It may never have to be used, and it is not creditable to have to use it by letting a car get beyond control; but the brake may give out or something else happen beyond the control of the motorman, so it should always be remembered, as it may save a sad accident some day. In case you have reversed and the fuse blows, the instant it is felt that the power has been shut off by the blowing of the fuse, put the controller around on one of the higher points named. This plan may also be used in case the brakes fail and the trolley comes off going down hill. It is a very violent way of stopping, and injurious to the equipment.

Hints on Saving Power.—It is not necessary that a man be powerful to control an electric car. At first he is apt to spend an unnecessary amount of energy at the brake. Power may be saved and the car would be subject to less wear and tear if handled not by pure strength, but by proper judgment of time and distance. It should be considered that as long as the controller is not on the "off" position power is taken into the motors and consumed. If a car is to be stopped, turn off the power some time ahead, because the energy taken into the motor does not disappear the moment the current is shut off. The motors and the car have

weight, and energy is stored in this moving body and this energy must be spent before the car can come to rest. Some men, because they have not the right judgment, set the brake the moment the controller is placed at the "off" position, and they must then work hard at the brake and consume the energy still stored in the moving car, by spending it partly in wear on them-

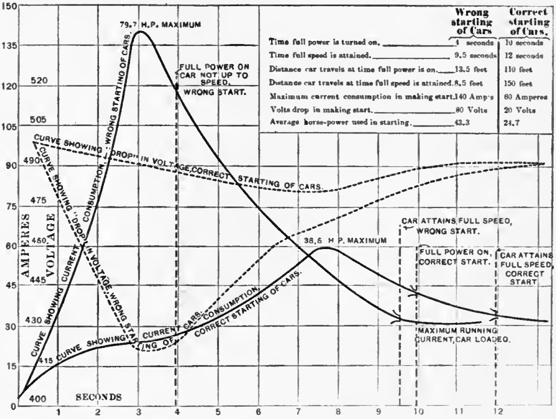


Figure 121—Curves Showing Power Required for Correct and Incorrect Handling of Controller.

selves, brakeshoes, car wheels, motors and gears. It means wear all around, without benefit to anyone.

A test (Figure 121) made by the author between a good and a poor motorman with the same motor car and same load, on the same dry summer day, showed that the better man used but one-half as much power as the other. What became of the extra energy used by the other man? The answer is found in the barn at

the end of the day. The man who uses the most power seems tired when he goes home in the evening, from the hard work he had at the brake; and an examination of the equipment will show the greater wear on brake-shoes, constant trouble with brakes, softer car wheels, which soon wear flat in spots, and frequent loose bolts, all caused by this extra expenditure of energy by the man of no experience or poor judgment. The simplest thing in the world is to cut off the power ahead of time and let the energy stored in the car spend itself by allowing it to propel the car by its momentum for half a block or so, when it easily can be stopped by setting the brake. What has been said here, however, is not always possible to do, and a motorman must use his judgment. For instance, if the pressure (voltage) is low, or many stops have to be made, or the motors have not speed enough for the schedule time set by the company, a motorman cannot act exactly as he would wish. But in these cases the conditions are not normal. Such rules can be used as a guide when a road is properly equipped and the schedule time for a round trip is so chosen, compared with the distance to be covered and speed of the motors, that the motors can accomplish their work easily.

When running up behind a team on the track and it is seen that the car will overtake it before it gets out of the way, do not crowd on speed and rush up behind it, as is often done, only to be obliged to put the brakes on hard to avoid a collision. Just as good time will be made and much muscle and power be saved by letting the car run along slowly enough to get the team out of the way before reaching it instead of bringing the car almost to a stop after having run up to it at full speed.

Should the wheels slip or skid on going up grade, bring the sand box into action, and if the car wheels continue to slip then throw the controller handle to the "off" position and turn it on again step by step. When the rail is greasy or covered with snow so that the wheels do not take hold of the rail, apply a little sand before starting the car. Use the sand sparingly and be sure that there is some left for future use.

Some Precautions Against Accidents.—When approaching curves, switches, turnouts or railroad crossings slow down the car so as to have it under control. It is best to have the controller at the "off" position and the right hand on the brake. The moment the wheels reach the curve, switch or crossing put on the power gradually, to carry the car over the curve or crossing. Never let the car stop on short curves such as are frequently found on city lines, unless special instructions from the company have been issued on this point. When taking curves or turnouts the conductor should be on the rear platform ready to replace the trolley should it jump the wire. If the trolley passes the curve or switch properly, the conductor should ring "go ahead"; if the trolley jumps he should ring "stop." If the conductor has given his signal that the trolley has jumped off the wire, the motorman should keep his controller handle at the "off" position until the conductor rings "go ahead."

When going around curves, crossings or other places where the car may jump the track owing to roughness of the roadbed, or where rails are laid very low in a gravel road, and stones may wedge in the rails, or when passing through flooded places or low places where the rails are covered with water, slow speed should be used. When going up grades, it is best to

put the controller on points where the resistance is cut out, and, further, the car should not be stopped or started on a heavy grade if it can be avoided.

When passing an overhead insulated switch or section insulator, place the controller always at the "off" position, unless on a grade or there are other instructions from the superintendent.

Going down grade have the controller handle at the "off" position, the trolley on the trolley wire and the brake set to such an extent that the wheels turn slowly (not slide) so that the car remains under control, slackening the hold on the wheels when the grade becomes less steep or tightening the grip of the brake-shoes should the grade become steeper. Should the car get beyond control or the brake suddenly give out, it may be necessary to resort to reversing the controller, as previously explained. It is a severe strain on the motors, but may have to be resorted to, to prevent an accident or to save lives. When so reversing keep the controller in the first notch should it be effective; if not, turn the handle very slowly to the higher notches, as the fuse is liable to give out and the control by means of current from the power station is gone. Should the fuse blow there is then, as before mentioned, only one more way to get the car under control, and that is to throw the controller to the last notch, which causes the motors to act as dynamos. This plan is available only when there are two or more motors on a car. The current is generated by the rotation of the armature in the field. The energy furnished is the momentum of the descending car, which is out of your control and disconnected from the power station. The current so generated acts by means of the armatures as a brake, and the car will slow up in the same measure as the

motors generate current. The means just described are important to know, but should never be resorted to except in extreme cases.

When stopping a car in the barn pull down the trolley one foot or a foot and a half and tie it; also see that both controllers are on the "off" position and open the overhead or canopy switch. If for any reason the trolley should be left on the wire in the barn some of the car lamps might be turned on, which will be a warning to the repair men.

Before starting see that the controllers on both platforms are on the "off" position. Never place tools, rubber boots or other wearing apparel, cotton waste or the like on the side below the seat where the motor cut-out or wire cable connecting controllers and motors are located. Keep this place clean and free from dirt and moisture.

When examining motors open the main or overhead switch and take care not to let water drop into the motor from wet clothing. When examining car motors, fuse, etc., always open the overhead switch to avoid shocks. When operating a car, any unusual noise heard should be located. Loose bolts should be reported and attended to, because by the fixing in proper time of these small irregularities, which are caused by jarring and constant operation of the car, grave trouble can be prevented, and a car will remain much longer in good repair if kept so and watched.

It is true that a "stitch in time saves nine." The writer has seen plants where cars were neglected, bolts could be picked up along the road, and on one occasion a car was stalled because the lower half of a field magnet had dropped down and was wedged against the stone pavement. Should a motorman notice irregu-

larities or defects on the overhead line or on the track, the matter should be reported.

When operating on a road with steep grades be sure that you are prepared in damp or slippery weather to be able to get sand from the boxes. It is not sufficient that there is sand in them; it should be seen that it is dry sand and that the valve is in such condition as to allow the sand to pass through.

Never shift the reversing handle unless the controller handle is on the "off" position, nor reverse when the car is in motion except to prevent an accident.

When leaving the platform be sure that the controller is turned off and remove the controller handle. When on the road they should be kept in the hand, and in the barn they should be left according to the rules given by the company. The reason the motorman should not leave the controller handle on the controller is that accidents are encouraged. The author has frequently seen that at country fairs, where people crowd into the cars at both ends, people are apt to strike the handle with baskets or coats held over the arm, and can in this way start the car unexpectedly. Keeping the handle in one's hand on such occasions leaves the motorman in full control of his car and up to the requirements of his duty and responsibility.

Young people do not realize the responsibility of the position of a motorman; they may think it fun to hide the handle when he has left the car for a moment. Persons acquainted with the motorman have taken such liberties when a car, for instance, was at the end of a track and had to wait for five or ten minutes. As the motorman is held responsible for his car he should always have it under full control, and leave it so no one can accidentally start it.

If at any time the power gives out in the power station, for instance, by the operating of a circuit-breaker, then bring the controller handle to the "off" position, close the lamp circuit and wait until the lamps light.

Before starting the car for a run, see that the brushes and brush springs are in position (unless there is someone else whose duty it is to keep the cars in readiness for the motorman). Before placing the trolley on the wire, look at both controllers and be sure that they are both at the "off" position. Do not run the car with the trolley pole in the wrong direction, because in this position it has no yielding properties when it strikes a hanger or suspension wire. If it jumps the wire it would bend the pole or cause trouble to the overhead wire.

The operation of the brakes is one of the most important duties of a motorman and one of the most difficult. Accordingly, it is treated in a chapter by itself.

CHAPTER X.

BRAKES AND THEIR OPERATION.

The brake is a most important device for the motorman, because its purpose is to control the car when the power is cut off and force it to slow up or stop at any desired place. The brake, when applied, consumes the energy stored in the car by the motors. This energy is overcome by the friction of the brakeshoes (Figure 122) on the car wheels. The better a motorman can estimate the distance and the less he has to use the stored energy by applying the brake, the more efficient is his service, and the less is the power wasted. To apply the power up to the last moment and immediately afterward use the brake is a wasteful performance, although when stopping on a grade or when a motorman has to make many stops and his time for a round trip is measured closely with respect to the speed of the motor in use, such action cannot be avoided.

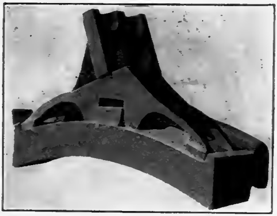


Figure 122—Brakeshoe and Head.

There are at present in use five kinds of brakes.

1. Hand brakes in which the power which draws the brakeshoes against the wheels is supplied by the strength of the motorman, either by the winding of a chain on a staff or, as on a few roads, by a long lever.

2. Momentum or friction disc brakes in which the momentum of the car furnishes power to draw up the brakeshoes through the medium of a friction disc or clutch placed on one axle.

3. Air brakes, in which the power drawing up the brakeshoes is compressed air acting against a piston.

4. Electric brakes, in which the retarding force is the electricity generated in the motors which are connected to act as dynamos, the motors in this case being used to stop the car as well as to start it and run it.

5. Track brakes, in which shoes carried at the sides of the truck are pressed against the top of the track rails with sufficient force so that the friction between the shoes and rail stops the car.

Hand Brakes.—While hand brakes are used on all electric cars, all but the smallest and lightest cars are now generally equipped with some kind of power brakes. Every truck has a brake mechanism consisting of various arrangements of rods, beams and levers by means of which the force applied to the brake handle or the brake levers is transmitted to the brakeshoes so that they may be pressed hard against the wheels. Different makes of trucks have their own styles of brake rigging. The number of different makes, however, is too great to permit a detailed description of them all, and as the general arrangement of all of them is more or less similar, a description of two or three different styles of brakes will suffice.

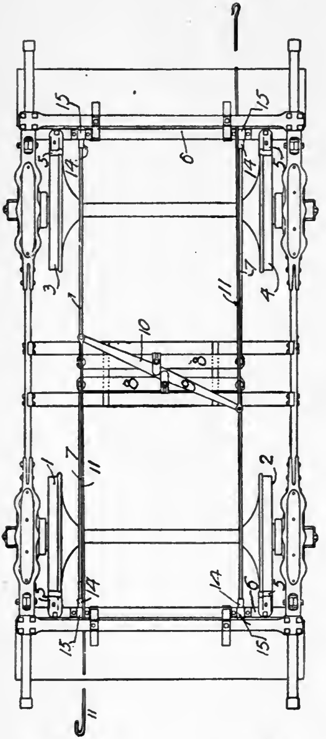


Figure 123.

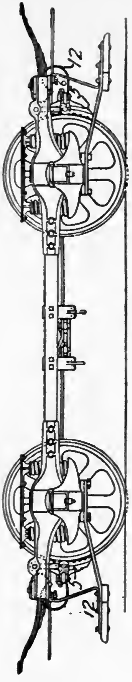


Figure 125.

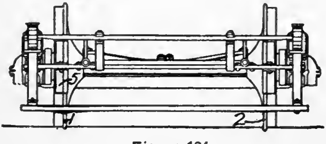


Figure 124.

Figures 123, 124 and 125 show three views of the truck equipped with hand brakes. Figure 123 is a top view, Figure 124 a front elevation and Figure 125 a side elevation. The brakeshoes, 5, are located close behind the car wheels 1, 2, 3 and 4, the normal distance between the brakeshoes and wheels being about one-eighth of an inch. The shoes are supported by brake-beams, 6, to which are fastened the brake rods, 7. The other ends of the brake rods are securely fastened to the cross beams, 8, which in turn engage at 9 with the equalizer bar. At the ends of the equalizer bar are secured the hook rods, 11, into which the brake chain is hooked. The chain, brake staff and handle are not shown in these drawings. A heavy spring, 12, is used to remove the brakeshoe from the car wheels when the brake is released. The action that takes place in braking the car is as follows:

When the motorman turns the brake handle around one or more turns he winds up the brake chain and pulls forward the hook rod, 11, thereby moving the equalizer bar, 10, which in turn moves the cross beams, 8, 8. These cross beams in moving toward each other move rods 7, and these in turn bring the brakebeams, 6, and shoes, 5, toward each other until the shoes rest firmly against the car wheels. When the brake handle is released, all the parts return to their former position. The spring, 12, assists in this latter work and helps to hold the brakeshoe away from the wheel.

It will be seen from this that all four brakeshoes act at the same time. It is necessary to provide an adjustment in every brake, because the brakeshoes wear and the slack caused by this wear must be taken up. In the truck just described this adjustment is made where the rods, 7, connect to the brakebeam at points

14, near the shoes. These rods have threaded ends that screw into sleeve nuts, 15, which are held in pockets provided for them in the brakebeam. A self-locking device prevents these ends from turning loose by the jolting of the car. The adjustment is made by turning the head of the nut with a wrench. The head is at the outer enclosed side of the nut, and turning it to the right, or clockwise, shortens the rod and brings the shoe nearer the wheel. The locking device does not interfere with turning the nut with a wrench, but it prevents the nut from turning due to the jolting of the car. These adjustments are placed near the brake-shoes, because this location enables the adjustment of each shoe separately, and consequently all the shoes may be regulated for an equal pressure on their wheels.

On double-truck cars, arrangements are made to apply the brakes on both trucks, so that each will be operated by one motion of one brake handle or one air brake cylinder. This is accomplished in various ways, generally by having either a fixed or floating lever in the center of the car between the trucks, to which the brake rods from each truck are connected. The central lever is then connected to the brake staff by means of a brake chain and rod, and by moving this rod and the central lever to which it is attached, the brakes on both trucks are operated simultaneously. Such an arrangement of the levers for double-truck cars is shown in Figure 126, and the following dimensions show the proportion of the different levers. The length of the floating lever, l, is 48 inches, and the distance, d, between the pins for the arch bar rods is 9 inches. The length, b, of the truck lever is 13 inches. With these dimensions of levers a pull of 65 pounds at the brake handle, which is 15 inches in length, gives a total brak-

ing pressure of 29,000 pounds, which is more than the weight of an empty car. The proportion of the levers recommended by the makers of these brakes is such as to make $(l \div d) \times (b \div c) \times (h \times 85)$ equal to the total weight of the unloaded car. The chain is not coiled around the brake staff on these brakes. Instead there are two chains running in a double sprocket wheel, which makes the operation of the brake very smooth

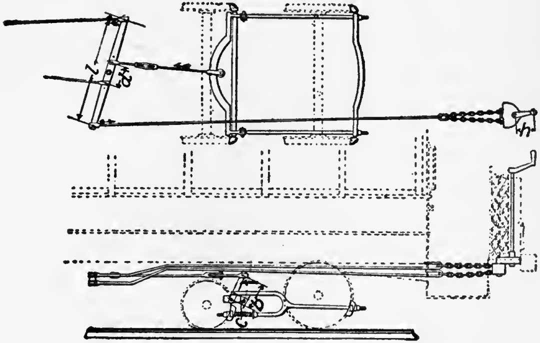


Figure 126—Brake Levers on One Truck.

and permits the motorman to feel even a slight touch of the brakeshoe against the wheel. If the working chain breaks, the safety chain comes into operation, thus preventing the disability of the brakes from this cause.

The object of these brake mechanisms for double trucks is to provide means for bringing an approximately equal pressure on all of the car wheels. This is necessary in order to secure the maximum braking effect, and also to prevent one set of wheels being

locked more firmly than the others, which would cause them to slide along the track without revolving and produce flat spots on the wheels.

Electric Brakes.—The electric brake has as its fundamental principle the utilizing of the live energy stored in the moving car to generate an electric current in the motors independently of the power-station current, and the use of this current to bring the car to a standstill. By means of the type B controllers, as described in Chapter VII, the motors are connected to act as dynamos. This current is sent through resistance and stops the car partly by its retarding effect on the motors themselves and partly by a magnetic friction disc mounted on each axle. If a car provided with an electric brake is to be brought to a stop, the action is as follows: The motorman first brings his controller to the "off" position and thereby disconnects the car from the line and power station; then by moving the handle around to the left of the "off" position to the special brake notches, the armature connections are reversed and the motors are connected to form a closed circuit through a resistance and the brake disc magnets, as shown in Figure 127. The motors running with the circuit closed in this way act as dynamos and generate current. This current tends to stop the motors and also to cause the magnetic clutch on the axle to act and aid in stopping the car.

To operate an electric brake requires a little practice on the part of the motorman, but when the principle is clear it is an easy matter. It first should be understood that the amount of current generated in the motors, and consequently the braking effect, depend on the speed at which the motors are running. If the brakes are to take hold evenly from the begin-

ning to end of a stop the resistance which is in the brake circuit must be cut out steadily. For example, when it is desired to stop a car that is running at full speed, the controller handle is moved to the first brake point. The motors start generating current to retard the car, but as the car slows down a little this current begins to weaken, and the handle should promptly be moved onto the next point to cut out some more of the resistance from the brake circuit and allow more cur-

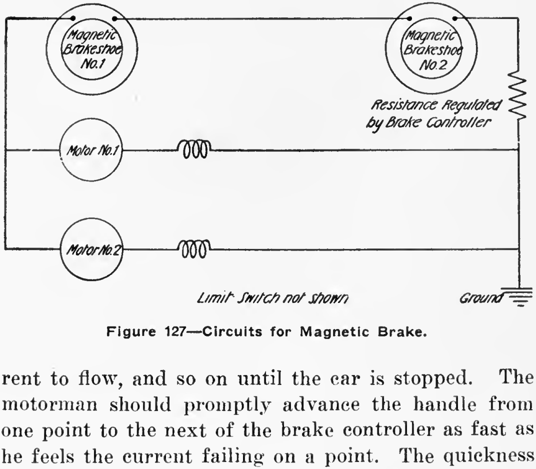


Figure 127—Circuits for Magnetic Brake.

rent to flow, and so on until the car is stopped. The motorman should promptly advance the handle from one point to the next of the brake controller as fast as he feels the current failing on a point. The quickness of the stop will depend on the rapidity with which the handle is moved from point to point, and in emergencies it may be found necessary to move two or more points at a time. There never is need to reverse on a car having an electric brake, because the brake will stop the car more quickly than reversing and is not so hard on

the machinery. On grades it is necessary to use the hand brake to hold the car while stopping, because the electric brake lets go as soon as the car stops.

Magnetic Brakes.—The Westinghouse magnetic brake consists of a combination of a track brake with the ordinary wheel brake. The track brakeshoe is placed between the wheels on a truck and so connected with the wheel brakeshoes that when the current in the electro-magnet of the track brake draws the shoe down

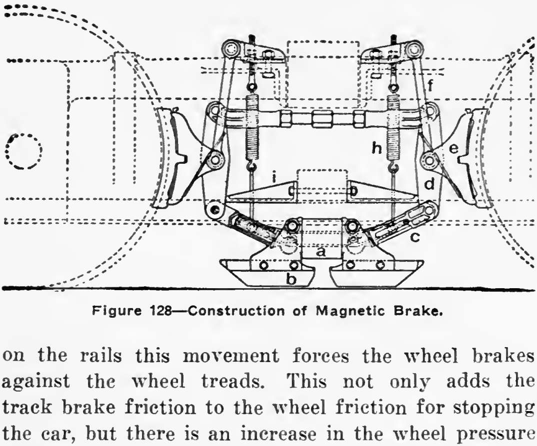


Figure 128—Construction of Magnetic Brake.

on the rails this movement forces the wheel brakes against the wheel treads. This not only adds the track brake friction to the wheel friction for stopping the car, but there is an increase in the wheel pressure on the rails due to magnetic action. The construction of this brake is shown in Figure 128, in which the parts of the truck are in dotted lines so as to more readily distinguish the brake apparatus. The electro-magnet, a, dividing the track brakeshoe, b, into two parts, is secured by pins to the two push rods, c, and suspended at the proper distance above the rails by the adjustable

springs, h. The push rods are secured by pins to the lower ends of the brake levers, d, d. These brake levers are connected at their upper ends by the adjustable rod, g, and at an intermediate point are pivoted to the brakeshoe holders and the hanger links, f, suspended from the truck frame. The push rods, c, are telescopic, as shown in the sectional view of the one at the left, so that a movement of the track shoe toward the right relative to the truck frame causes the wheel brakeshoe at the right to be applied to the wheel and the connection, g, to be moved to the left, thereby applying the wheel brakeshoe at the left. The stop, i, prevents the lower end of the brake lever at the left from following the track brakeshoe. A relative movement of the track brakeshoe to the left is obviously accompanied by application of the wheel brakeshoes through corresponding movement of the parts in the reverse order.

The brake-controlling device may be incorporated in the running controller or may be a separate device, placed by its side and operatively interlocked with it, so that neither can, through carelessness, be caused to interfere with the operation of the other. These controllers, type B, were described in the previous chapter. In the operation of the apparatus, the current is supplied by the motors, running in multiple as generators, and is divided between the electro-magnets and the diverter, in such ratio as to cause the track brakeshoes to be drawn upon the rails with a force proportionate to the braking requirements. The frictional resistance of the rails to the motion of the track shoes causes the wheel brakes to be applied with corresponding force. Thus, to the ordinary retardation of the wheel brakes is added that of the track brake. The

force of application depends upon the current and upon the electro-magnets operating the brakeshoes. The attractive force of the rails upon the magnets is under the control of the motorman up to a limit of 150 pounds per square inch of brakeshoe surface in contact with the rails. The strength of the magnet is limited by the sectional area of the rail, acting as its armature; and where the weight of the car makes desirable a magnet of greater strength, the track shoe is divided into three parts, instead of two, and wound to form a three-pole magnet, or two electro-magnets with one common pole. With this brake the diverters or resistances are arranged in two sets, one inside and the other outside of the car. Those inside are used to heat the car, for which the starting current and braking current are ample. The two sets of diverters may be so combined that any desired portion of the heat generated may be used in the car and the remainder, if any, pass into the open air.

The friction of the track brakeshoe also may be adjusted to some extent through the angular inclination of the push rods, c. This would throw some of the weight of the car upon the track shoes, the levers, d, being correspondingly adjusted to reduce the wheel brakeshoe pressure in proportion as the weight is transferred to the track shoe. The current declines with the speed during a stop, and in bad weather, when the condition of the rails is liable to be accompanied by wheel sliding, the braking force operating the wheel brake is correspondingly reduced, so that the force of application of the wheel brakes is automatically proportioned to the rail friction which rotates the wheels. If by chance the wheels should slide upon the rails, the interruption of wheel rotation cuts off the track-magnet

current, through which the pressure of the brakeshoes upon the wheel is instantly relaxed, and rotation of the wheels is resumed without injury or serious loss of time.

Straight Air Brakes.—The straight air-brake system has been universally adopted as the standard form of power brake for electrically propelled cars, either when operated as single units or when hauling one or two trailers. The factors which have led to its universal use are:

(1) Positive control, (2) Simplicity, and (3) Ease of manipulation. All of these features are possessed by this system to a higher degree than by any other.

The straight air-brake system consists essentially of a source of compressed air, a brake cylinder, and a simple valve under the direct control of the motorman, the use of which is to control the admission and exhaust of the compressed air to and from the brake cylinder as desired. A diagram showing the connections of the different parts of one system is shown in Figure 129.

This straight air-brake equipment consists of the following parts, as indicated by numbering:

1. Electric motor-driven air compressor.
2. Box for compressor.
3. Cage for supporting box and compressor under a car.
4. Insulating coupling.
5. Reservoir for storage of the compressed air.
6. Automatic electric governor.
7. Cover for governor.
8. Insulating coupling.
9. Non-arcing enclosed fuse to protect the compressor motor.
10. Brake cylinder with hollow piston rod ar-

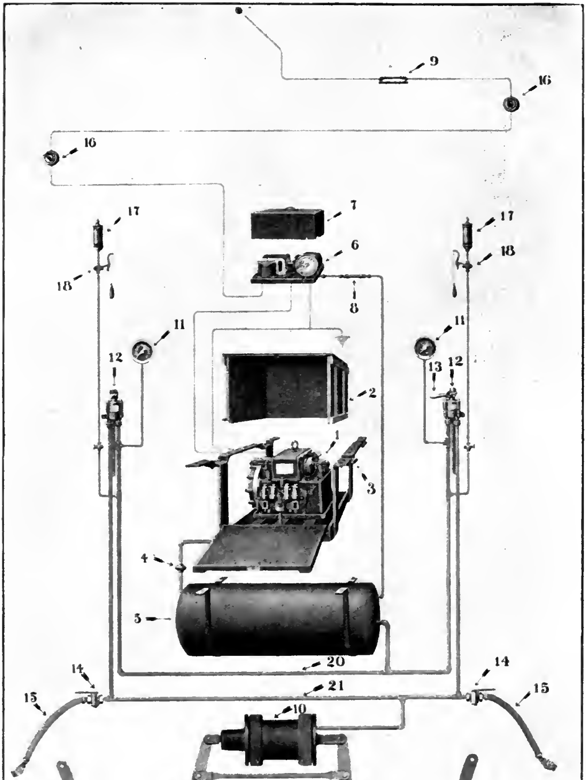


Figure 129—Parts of Straight Air-Brake System.

ranged to allow of the hand brake being easily applied through the same lever system.

11. Pressure gauge.
12. Engineer's valve for admitting air to, and releasing it from, the brake cylinder.
13. Handle for engineer's valve.
14. Cut-out cock for trailer connection.
15. Hose and coupling for trailer.

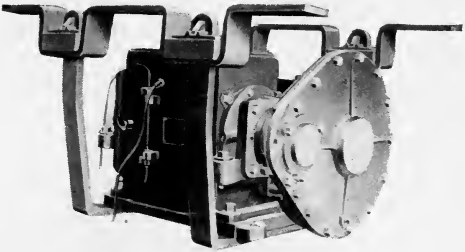


Figure 130—Air-Compressor Motor In Cradle.

16. Switch.
17. Whistle.
18. Independent valve for whistle.
19. Brake lever rigging.

20, 21. Pipe fittings.

The application of the brakes by admission of compressed air from the reservoir to the brake cylinder is effected by opening ports in an operating valve, thereby causing the piston in the cylinder to move outwardly, applying the brakes with a greater or less degree of force, depending upon the size of the port that is used, and the length of time that it remains open. Thus the motorman is able to apply the brakes with such pres-

sure, up to the maximum, and in as small a space of time as is desired. After admitting air to the cylinder, if the handle is placed in the position where all ports are closed, the air already admitted to the brake cylinder is retained there, thus holding the brakes applied. A further movement of the handle to the release position connects the brake cylinder with the atmosphere, permitting the air to escape, thus releasing the brakes. A graduated release of the brake may be obtained by permitting a portion of the air in the cylinder to escape and then returning the handle to the position where all ports are closed.

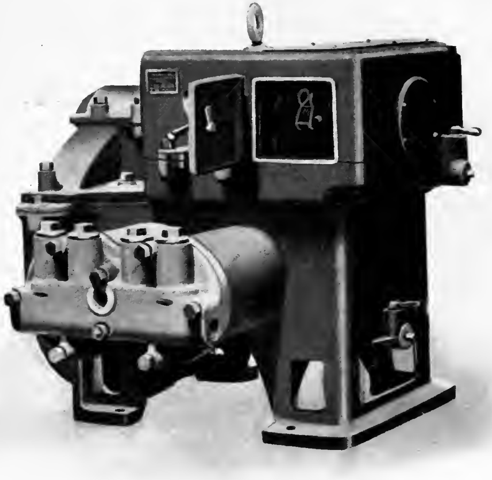


Figure 131—Air Compressor.

Air Compressor.—The air compressor is directly mounted on two oak planks supported in a cradle made of wrought-iron bars. The cradle is suspended beneath the car from the floor beams, as shown in Figure 130.

The air compressor (Figure 131) consists of two cylinders, with single-acting pistons connected to one crank shaft which is driven by an electric motor through gears. One piston compresses air while the

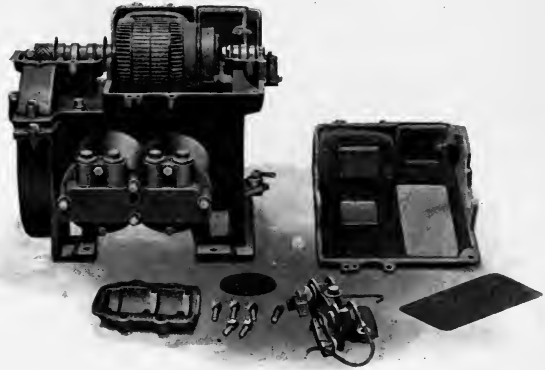


Figure 132—Air Compressor Disassembled.

other draws it into the cylinder. A disassembled view of the motor compressor is given in Figure 132.

Compressor Governor.—The current that is used by the motor driving the air pump is controlled by an automatic governor, one type of which is shown in Figure 133.

The duty of the governor is to automatically control the operation of the air compressor driven by its

motor, stopping it when the desired maximum pressure is reached, and starting it when the pressure falls below a set minimum. The difference between these pressures is usually 10 pounds. It does this by automatically making and breaking the electrical circuit to the motor as the pressure falls below or rises above the pressure for which the governor is set. It thus furnishes a steady supply of air for the use of the motorman in stopping the car.

The brake cylinder is shown in Figure 134 in con-

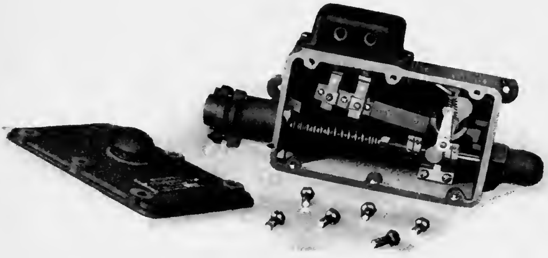


Figure 133—Oil-Break Air-Compressor Motor Governor.

nection with the hand-brake rigging as installed on double-truck cars. The reader will note that the same system of levers serves for both air and hand brakes.

Motorman's Valves.—The motorman's operating valve is the device by which the motorman controls the application of the brakes and is a highly important part of the air-brake equipment. The duty which the motorman's valve performs is to connect reservoir pipe, train pipe and exhaust in such a way that air will flow through the reservoir pipe into the train pipe, passing thence to the brake cylinder, or will issue from the train

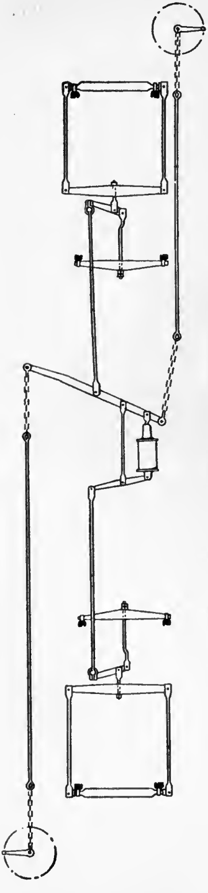


Figure 134—Air and Hand Brake Rigging—Double-Truck Car.

pipe to atmosphere, depending upon whether it is desired to apply or to release the brakes.

The appliance essentially consists of a sliding or rotating valve with ports on its lower face so arranged that they register at the proper times with suitable ports in the valve seat to make the necessary connections for the desired braking application. The valve seat contains ports which connect with the main reservoir, brake cylinder and atmosphere, respectively.

The valve is manipulated by turning a removable handle fitted to the end of the valve stem or spindle; this handle moves through an arc of about 120 degrees in turning from release position at the extreme left to emergency position at the extreme right. The handle can only be inserted or removed when the valve is in lap position and all ports are blanked so that there is no connection whatever between any of the three ports in the valve seat. When the handle is removed the mechanism is securely safeguarded by a pro-

tecting shield, which prevents meddlesome persons from getting a grip on the operating spindle either with the hand or with a wrench.

Figure 135 shows a top view of one style of valve and has indicated on it the various positions of the operating handle for the different stages of setting and releasing the brakes.

Operating Instructions.—The motorman should thoroughly familiarize himself with the air-brake equipment so that he may obtain the full advantage of the most efficient operation. He should discard the notion (if he happens to be unfamiliar with the details of the apparatus) that the air brake is difficult and intricate to understand in its details, because it is not. Following is a summary of the main points for his guidance:

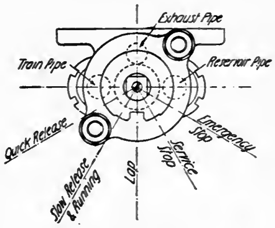


Figure 135—Valve Positions.

1. To start the compressor, close the canopy switch. This will automatically close the governor so that current will pass from trolley to ground through the motor, thus driving the compressor.

2. Should the compressor refuse to work under this condition, the fuse may be blown. If so, do not put in a heavier fuse than specified for the size of the compressor. If the fuse is in order, he should try to locate the trouble, or should report the matter to the proper person.

The engineer's valve is made with a detachable handle which is only removable in what is known as

"lap position," in which position the valve is neutral in the same manner as the main controller is by removing the reverse handle.

A service application of the brakes is effected by moving the handle of the engineer's valve to the first notch on the right. As soon as sufficient pressure is brought against the wheels, the handle may be moved back into lap position, whereby the brakes remain set at that pressure. If it is desired to increase the rate of braking the above operation may be repeated. By moving back the lap without releasing, the handle may be removed and the brake released from the other end of the car.

By moving the handle from lap position to the first notch on the left a slow release of the brakes is effected, which release may be checked in the same way by moving the handle back to lap position, the same as in service applications of the brakes.

An emergency application is effected by moving the handle to the extreme right. This opens a large port between reservoir and brake cylinder, giving an immediate full reservoir pressure in the cylinder and an instantaneous application of the brakes.

By moving the handle from lap position to the extreme left a large port is opened between the brake cylinder and atmosphere, effecting an immediate release of the brakes.

When the brakes are not being applied or released, the handle of the engineer's valve should always be on the first notch to the left, or that of slow release.

The leverage and total pressure on the brake cylinder is so proportioned that under ordinary circumstances, with a dry rail, the wheels cannot skid. If the rail is in bad condition for stopping, the leverage and

pressure being the same as under normal conditions, would probably skid the wheels, if the brake cylinder is charged with the full pressure. In such instances care should be taken not to slide the wheels by introducing too much pressure to the brake cylinder. If the wheels slide, which can be instantly felt, the handle is moved over to slow release, letting out air until the wheels again revolve, then back to lap, and release again just before the car comes to a dead stop. This will prevent the disagreeable jar which follows if a car comes to a dead stop with the brakes applied.

The quickest stop obtainable is made by applying to the wheels, throughout the stop, the greatest pressure possible without causing them to slide on the rails, and the higher the speed the greater the pressure that may be applied without danger of sliding. Thus it is evident that in order to make a quick stop, full pressure should be applied at once, and gradually released as the speed falls; this method will also give a smooth stop, as the rapid reduction of speed at the end of the stop, which throws passengers, is avoided. Therefore, in making a service stop, admit 25 or 30 pounds of air pressure to the brake cylinder quickly at the beginning of the stop by partially opening the large port, and release it little by little as the speed drops, retaining about 10 pounds in the cylinder till the car stops. A little experience will show the distance required in which to make a stop from a given speed so that all stops will be made quickly, smoothly and with but one application of the brake.

A succession of applications and releases while making a stop imparts a very disagreeable motion to the car, is most wasteful of compressed air, and is bad practice in every respect. For the emergency stop

admit full pressure (about 60 pounds) immediately, without even waiting till the controller is turned off; then apply sand and release a little of the pressure as the speed drops.

Upon receiving the signal to go ahead, turn the handle to the release position before turning on the electric power. When descending a grade a beginner generally makes the mistake of putting the brake on too hard at the start; it cannot be expected that the instant the brake is applied the car will take the speed desired; make an easy application at first, hold the handle at "lap" and give the car time to feel the effect of the brake, then, if the speed is still too high, let in a little more air; repeat the operation as often as necessary until off the grade, in case it is a long one.

When leaving a car, always set up the hand brake, as some one might tamper with the cut-out cocks. Before starting from the car barn, be sure all cocks are properly set and that there is a good supply of air in the reservoir. Insert the handle in its socket in the operating valve and throw it around to emergency, then back to release, to see that it works freely. Try the air brake both in "service" and "emergency" to make sure that it has not been left improperly connected, etc. After this trial, and as long as proper pressure is maintained, the brake may be relied upon to perform its duty.

Care must be taken in making up trains, that all hose couplings are thoroughly united so that the air will apply throughout the entire train. All the cut-out cocks must be opened, except those on the rear of the last car and on the front of the motor car, which must be closed. In uncoupling the cars close the cocks and disconnect the hose before pulling the drawbar pin.

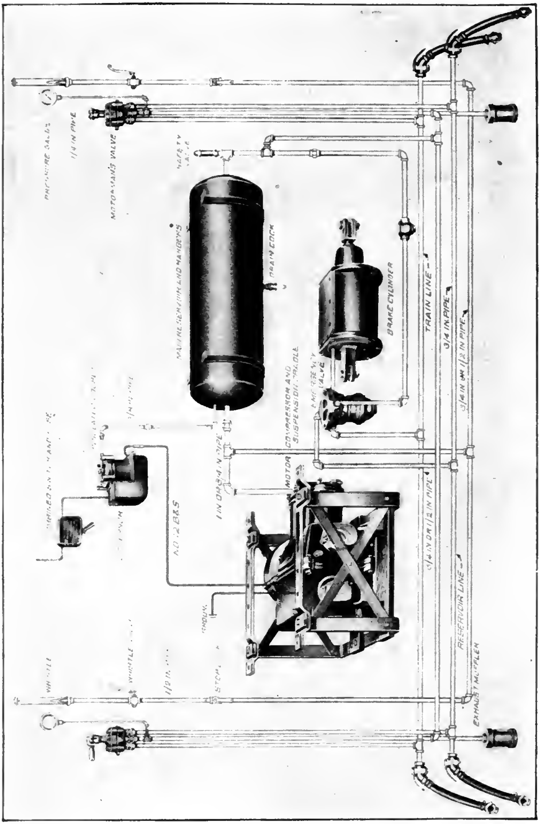


Figure 136—Emergency Straight Air-Brake System for Motor Car.

The air brake is essentially a labor-saving device for the motorman, and it is scarcely necessary to ask for his co-operation in the use and care of it. Its success and general adoption for fast and heavy street railway service depend very much on his interesting himself in its use, and having an intelligent understanding of the functions of the various parts, that he may readily notice when anything about them is not working properly, and report the trouble before it becomes serious. Like the other apparatus of a street car, the air brake will not operate indefinitely without attention, and the old proverb of "a stitch in time saves nine" applies in this case as in all others.

Emergency Features.—The emergency straight air-brake system for the combined operation of single cars and short trains has been developed by the air-brake manufacturers. The apparatus required does not differ greatly from that of a straight air-brake system. The application and release of brakes, except in cases of emergency, is made in the same way, that is to say, air is admitted or exhausted from the brake cylinder directly through the motorman's valve. Two lines of piping, called the reservoir and the train lines, run through the train connecting the motorman's valve and emergency valves. Figures 136 and 137 illustrate the system of piping connections used in one manufacturer's type of emergency straight air-brake equipment. Figure 136 shows the equipment for motor cars and Figure 137 shows the equipment for trail cars.

The desirable feature of this system is obtained by the use of the emergency valve. The brakes are applied automatically in case the reservoir line pressure is suddenly reduced, as would happen in an emergency

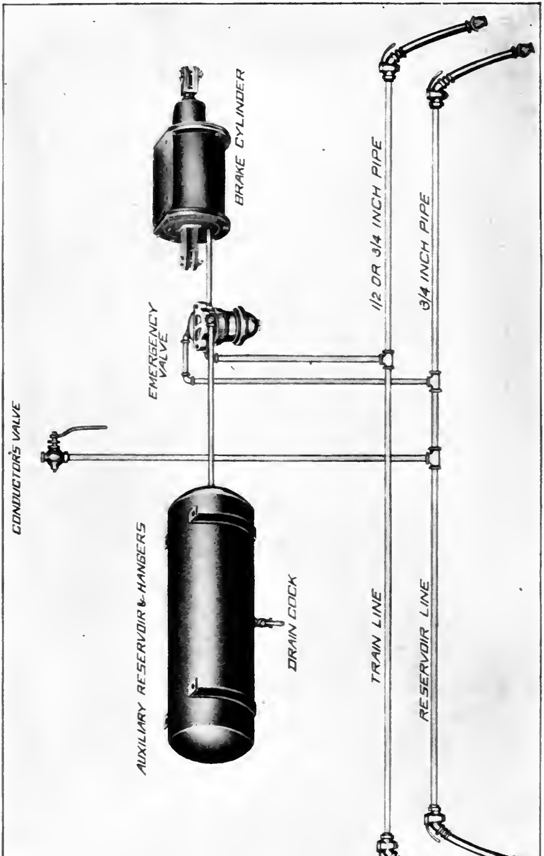


Figure 137—Emergency Straight Air-Brake System for Trail Car.

application or if the train parts or a coupling hose should burst.

With the straight air-brake system the train line is not always under pressure, and the uncoupling of the hose connections between cars is not an uncommon accident and leaves the trail cars without air brakes. With the emergency straight air-brake system, a break in the train line has no effect on the emergency valve, which still can be operated as ordinarily by throwing the motorman's valve handle to the emergency position.

Automatic Air Brakes.—The automatic air brake, first designed for steam railway trains, is now coming into general use for those electric railways that operate more than two cars in one train.

The essential difference between the automatic and straight-air traction brake systems is that in the latter air is admitted to the train pipe to apply the brakes and allowed to escape from it to release them; whereas, in the automatic system, air is allowed to escape from the train pipe in order to apply the brakes, and is admitted to it again to release them. With the straight-air equipment the train pipe is never under pressure except during an application of the brakes, whereas the automatic train pipe is under pressure, except in emergency applications, and this pressure is greatest when the brakes are released.

Each brake cylinder in the automatic system is provided with its own reservoir, called the auxiliary reservoir, in which air is stored for use in this cylinder only. The reservoir which receives the compressed air directly from the compressor is, in this case, called the main reservoir, and furnishes the air to charge the train pipe and auxiliary reservoirs, and to release the brakes.

The connection between each brake cylinder and its auxiliary reservoir and the train pipe is made through a triple valve in a manner to be explained presently.

Figure 138 illustrates the essential parts of the automatic brake system and their relative location, as usually applied to trains of two or more cars.

The operations of the brake are controlled by the triple valve, the primary parts of which are a piston and slide valve. A moderate reduction of air pressure in the train pipe causes the greater pressure remaining stored in the auxiliary reservoir to force

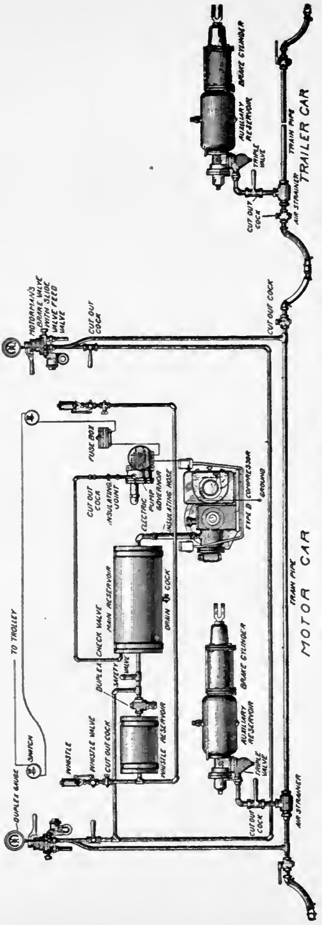


Figure 138—Westinghouse Air-Brake System for Motor and Trail Cars.

the piston and its slide valve to a position which allows the air in the auxiliary reservoir to pass into the brake cylinder and apply the brake. A sudden or violent reduction of the air in the train pipe produces the same effect, but, in addition (if a quick-action triple valve), it causes supplemental valves to be opened, permitting the air from the train lent reduction of the air in the train pipe producing a brake-cylinder pressure about 20 per cent greater than that derived from the auxiliary reservoir alone, and producing a practically instantaneous application of the brakes throughout the train. When the pressure in the train pipe is subsequently increased above that remaining in the auxiliary reservoir, the piston and slide valve are forced in the opposite direction to their normal positions, thereby restoring communication between the train pipe and the auxiliary reservoir and permitting the air in the brake cylinder to escape to the atmosphere through the triple-valve exhaust port, thus releasing the brakes, and at the same time recharging the auxiliary reservoirs.

When the motorman wishes to apply the brakes, he moves the handle of the motorman's brake valve to the right, which cuts off communication with the main reservoir and permits a portion of the air in the train pipe to escape; to release the brakes, he moves the handle to the extreme left, which allows air to flow from the main reservoir into the train pipe, restoring the pressure therein.

A device called the conductor's valve may be placed on each car, to which is attached a cord that runs throughout the length of the car. In case of accident, by pulling this cord, the valve is opened and discharges air from the train pipe, applying the brakes.

When the train has been brought to a full stop in this manner the valve must be closed.

Should a train break in two, the escape of the air in the train pipe applies the brakes automatically to both sections. The brakes are also automatically applied through the bursting of a hose or pipe. In fact, any material reduction of pressure in the train pipe applies the brakes, which is the characteristic feature of the automatic brake.

An angle cock is placed in the train pipe at each end of every car, which must be closed before separating the couplings, to prevent an application of the brakes. A cut-out cock is also placed in the crossover pipe leading from the train pipe to the quick-action triple valve, and also in the train pipe near the motorman's brake valve, within convenient reach of the motorman. The former is for the purpose of cutting out, or rendering inoperative, the brake apparatus upon a car, if for any reason it should become disabled; the latter is for cutting out the motorman's brake valve upon all motor-cars except the first, in case two or more are attached to the same train.

Operation of Automatic Air Brakes.—After making up a train the brakes should always be tested in the following manner: With the brake-valve handle in the running position, charge the train line and auxiliary reservoirs; to determine when the charging is complete, place the brake-valve handle in lap position and when everything is charged, the black hand of the duplex gauge will not fall. The motorman should then apply the brakes by moving the handle of the brake valve to the service application notch until a reduction of 10 pounds has been made in the train line. Then, after placing the brake valve on lap, the motorman should remove the handle, and, carrying it with

him, proceed along the length of the train and see that the cylinder piston of every car has moved out such a distance as to indicate that the brakes are properly applied on all cars of the train. He should then release the brakes from the last cab at the rear end; then again remove the handle and return to the front end, examining all cylinder pistons. He should be careful to see that they have moved back to full release, thus indicating that all brakeshoes hang free.

For any purpose except testing brakes or making an emergency application, the first reduction in train-line pressure should be from five to seven pounds. After the first five to seven pound reduction, the best results are obtained by not using more than three or four pounds at any one reduction; this, however, must be governed entirely by the circumstances. As from 13 to 15 pounds reduction in train-line pressure causes an equalization of auxiliary-reservoir and brake-cylinder pressures, when making a service application, thus fully applying the brake, a further reduction in train line is simply a waste of air. The results of such a waste are that the brakes are slower in releasing; they fail to release simultaneously; they cause shocks to the train upon stopping; and they seriously overtax the compressor.

In making the ordinary service stop, two applications generally should be made. The use of two applications instead of one in making a service stop is better because this method of handling the brakes quickly brings the train down from a high to a low speed, is a safeguard against skidding of wheels, insures greater accuracy in making stops and permits the train to be brought to a standstill with a light reduction of pressure on the second application.

In releasing the brakes after making an applica-

tion in a service stop with the intention of immediately making a second application, the brake-valve handle should be moved to the full release and at once returned to the lap position. In making ordinary station stops a partial release of the brakes should be made at a sufficient time before the train comes to a standstill to avoid the backward lurch. Immediately upon the train coming to a standstill move the handle to full release position until the train line is charged to maximum pressure, then bring it back to running position. This also applies at all other times when the brakes have been applied and full release is desired.

In making full release of the brakes the brake-valve handle invariably should be moved to the full-release position. If the brakes release after a service application, examine all the brake valves in the train until the trouble is located. Either a brake valve has not been fully lapped or has a rotary valve leaking.

In case of emergency when it is essential to stop the train in the shortest possible distance, the handle should be thrown to the full emergency position and left there until the train has come to a stop, or the danger is passed. If the motorman has the brake partially applied in service application, and should be suddenly flagged, he should put the valve handle in the emergency position and leave it there until stopped. As a last resort to prevent collision or to save life, a motorman may reverse the motors. The reverse handle should be thrown into opposite direction and the controller handle moved to the second notch, which notch is usually found to have the greatest retarding effect. Motors may also be reversed in the event of the brakes being inoperative, but in ordinary service conditions motormen must never reverse the motors.

In case the brakes apply suddenly without apparent cause, the motorman should place the brake-valve handle in lap position until a signal is given to release the brakes. This prevents the escape of main reservoir pressure, thereby providing for a prompt release of the brakes.

A burst train-line hose or train pipe, or the breaking in two of the train, will apply the brakes; in that event close the train-pipe cock immediately ahead of the break and release the brakes to the rear of it by opening the release valves in the auxiliary reservoirs. The brakes ahead of the closed train-pipe cock can be released by the motorman and operated to handle the train until the fractured hose can be replaced.

In setting off cars the train-pipe cocks should be closed first and the hose parted by hand and hung up properly; never leave the hose to be jerked apart by the separating of the cars. Before setting the hand brake on the set-off car make sure that the air brake has been released. The foundation brake rigging of some cars is so constructed that the hand and power brakes pull against each other, in which case if the hand brake is set up with the air brake applied, the leaking off of the latter would release the brakes.

Storage Air Brakes.—One system uses compressed air which is stored in tanks, but is not compressed upon the car, as previously described. At the car barn or other central point a storage tank is provided containing compressed air. The tanks on the car are filled from this storage tank in a few moments. A tank capacity is provided on the car to be sufficient for from 300 to 500 stops, or several round trips over an ordinary city route. The initial pressure in the main reservoir on the car is usually 300 pounds per

square inch; by a reducing valve this is lowered to 50 pounds or less, according to the speed and weight of the cars. At this pressure the air enters the auxiliary reservoirs on the cars. From the auxiliary reservoir to the brake cylinder the air is controlled by the engineer's valve. The brake cylinder is provided with two pistons so adjusted as to be pressed toward each other through the agency of a spring, or other similar means. The motorman's valve provides for connecting the air supply or reservoir to the space between the pistons whereby the pistons may be separated against the tension of the spring to apply the brake when it is desired.

To release the brake a controlling valve is operated to cut off the space between the pistons from the air supply reservoir, and to connect it with the air space of the cylinder behind the pistons; thus the pressure on the opposite side of the piston is equalized and the springs permitted to return to their normal positions.

The storage air brakes are operated in practically the same way as other straight air brakes.

Hints on Handling Brakes.—The description of the brake mechanisms has been given more particularly for those motormen operating cars on the small country roads where frequently they are called upon to attend to such mechanical matters. In large cities and on large roads special inspectors are provided, and the author wishes to impress especially on those motormen who have inventive faculties, or imagine they have, or those who like to do tinkering, that they should touch absolutely nothing about the car equipment unless ordered by the road officers or regulations to do so. The company cannot afford to have a man experiment with its cars, especially when mechanics are employed to attend

to all irregularities on the car or truck. Inasmuch as this book is intended to tell a man how he should qualify himself for the position, it must not only tell him how to get a position, but also how to keep it. However much a man might desire to fix his car, it is not worth while to risk his position if he acts against the rules of the company in doing so.

While starting a car from the barn try the brakes, to see if they are right. Always be sure that the brakes are fully off before starting the controller. On grades it will be necessary to start the controller the instant the brake is released. There is usually some slack in the brake chain with hand brakes unless the shop men keep them closely adjusted.

It should be the constant effort of the motorman to avoid locking the wheels so that they slide or skid along the rail. There are two good reasons for this. In the first place, the instant the wheels begin to slide on the rails the braking or retarding force is reduced, or, what is the same, the motorman loses more than half his retarding power. This has been fully proved by experiment and by experience. In the second place, there is danger that by this sliding along the rails flat places will be worn on the wheels and rapidly will pound with every turn of the wheels and quickly grow worse, so that the noise becomes unbearable to the public and the wheels must be turned down at considerable expense or thrown away. A flat wheel on a car, therefore, is no credit to a motorman, and on some roads the penalty for a flat wheel is suspension. It is often hard to avoid sliding the wheels when there is sleet or mud on the rails, but this should be remembered above all: never turn on sand after the wheels have commenced to slide without first letting up on the

brakes so that the wheels can turn. The safer plan when stopping on a slippery rail is to apply sand at the same time the brakes are applied. Remember that the car can not be stopped so quickly by sliding the wheels as by putting on the brakes firmly without sliding them. In coming to a steep down grade be sure to slow up before reaching the incline and set the brakes gradually. If the wheels get to sliding on the grade loosen up on the brakes until they begin to turn again. Cars have run away down hills because motormen have lost their heads or failed to know and remember this point.

The wear or lasting qualities of the brakeshoes and the power taken from the power plant by a motorman to run a car depend to a considerable extent on his proper judgment of time and distance. The less he absorbs the stored energy with the brake the smaller will be the wear on brakeshoes and car wheels and the smaller the power taken.

It is not a good plan to make gradual stops by applying the brakes lightly a long distance back of where you want to stop, as you lose time in getting over the road in this way and require more power in making up for it. Let the car drift with brake entirely off until a short distance from the stopping place, and then apply them hard enough to make a comparatively short stop without sliding the wheels or making it uncomfortable for the passengers.

CHAPTER XI.

HOW TO REMEDY TROUBLES.

On many large roads the motormen are expected to do nothing beyond operating their cars, and whenever trouble occurs to a car on the road it is pushed in by the next and the repair men at the barn attend to the repairing. A motorman should, of course, always abide by the rules of his company, and if it forbids the opening of motors or controllers by motormen the author does not mean these instructions to interfere in any way with rules which may seem necessary to the officers of large systems where the motormen are not all well posted and where inspectors are employed whose special work it is to remedy slight troubles and where mischief may be done by the tampering of those who do not understand the apparatus. Nevertheless, there are many small roads where a knowledge of how to remedy troubles is needed, and even on the large roads mentioned the man who understands his car can save many delays if he knows how to report troubles intelligently.

In enumerating many of the troubles to which the cars and motors are subject and giving instructions for their temporary remedy, the author wishes to place in the hands of the motorman facts and means which

are helpful for such an occasion. However, no one should think that, without practical experience, by simply reading these lines, he can manage a car as well as a man who has been operating one for years. Practical experience is absolutely necessary, but in connection with it this chapter will be very helpful to the motorman.

A great deal must be learned by actual experience, and success in economical operation on a car line depends partly on the watchfulness of the motorman. While operating his controller he can readily detect irregularities, first, by the way the motors take the current when the controller is operated, and secondly when the car is under way, by the sound of the motors.

The economy which can thus be accomplished lies in the fact that loose bolts, a loose connection and the like are easily tightened. These are small troubles, caused by constant jarring of the car, which are easily attended to. However, if the car is not watched bolts will be lost, bearings will come loose, the armature revolving at a high rate of speed may be rubbing against the field magnet poles, or a wire working out of its connection may cause a short circuit and blow the fuse, etc. It will be readily seen that these small troubles, if not attended to in time, are the causes of others far more serious, yet a turn of the wrench or the screw-driver in proper time may easily prevent such troubles on the road. The well-known rule, "a stitch in time saves nine," should be remembered at all times, and besides this one: "cleanliness is next to godliness." Keep the motors, connections and contact terminals clean and dry. Before working around the electrical apparatus pull off the trolley and open the overhead switch.

Failure of the Car to Start.—If the car fails to start when the controller is "on" and both overhead switches are closed, the trouble is due to an open circuit, and probably to one of the following causes:

1. The fuse may have blown or melted. Open an overhead switch or pull off the trolley and put in a new fuse, removing the burned ends from under the binding posts before doing so. Never put in a heavier fuse than that specified by the company, as it might result in damage to the equipment by allowing too large a current to flow. The fuse may blow because of some trouble on the car, as will be explained a little further on.

2. On a dry summer day, when there is much fine dust on the track, it happens that the car wheels do not make proper contact with the rail and the car fails to start. In such a case try to establish contact by rocking the car body. Should this fail to work, the conductor should take the switch bar or a piece of wire and, holding one end firmly on a clean place on the rail, hold the other against the wheel or truck. This will make temporary connection until the car has started. The conductor should be sure to make his rail contact first and keep it firm during this operation or he may receive a shock.

3. If the track conditions apparently are good, it may be that the car stands on a piece of dead rail, a piece of rail on which the bonding has become destroyed. In that case the car conductor would have to go to the next rail section with a piece of wire to connect the two rails and then order the motorman to start his car.

4. A brush or two may not have been placed, or, if placed, may fit too tightly in the brush holder, so

that the springs do not establish contact between the brush and the commutator. If this is the case, remove the brushes and sandpaper them until they go into the brush holder easily.

5. The contact fingers on a controller are rough, burnt, and perhaps bent so that the drum cannot make contact. It may also be due to wear on both the contact surfaces of the drum and the finger, which may have been burnt and worn away to such an extent that contact is not established when the controller handle is placed in the first notch. Try to smooth the burnt surface with sandpaper and bend the fingers or contacts into their proper position. Should this fail, then operate the car with the other controller. In this case the conductor should be on the front platform to handle the brake and give orders to the motorman when to start and stop, as the occasion requires. Under these conditions the car should never be allowed to travel at a high speed.

6. A loose or broken cable connection. This can be located and placed and fastened in its position. It is, in most instances, a cable connected to one of the motors, rheostat or lightning arrester, and very seldom in the controller stand.

7. A burnt rheostat. A rheostat may have received too great a current for some time and the first contact terminal may be broken. In such a case, if temporary connection cannot conveniently be established, the car will not start at the first notch, but at the second it will start with a jerk.

8. If the car refuses to start on the first contact, but starts all right on the second and acts normal thereafter, then there is an open circuit in the rheostat, either internally, or the first cable connection is broken.

It may also be due to a worn controller and the contacts may be blistered or burnt. Move the controller handle slightly beyond the notch or go direct to the second notch.

9. The field coil of a motor may be grounded so that the fuse blows whenever the current is turned on. Cut out the faulty motor, as explained in Chapter VII.

10. Armature or commutator grounded. Cut out the motor as in case 9.

11. The lightning arrester is grounded by dirt between the discharge points. Remove the dirt, as the fuse will blow as long as the trouble exists. Should this not be possible then disconnect the lightning arrester, ground wire, insert fuse and go ahead. The trouble lies in the arrester.

12. The car starts and the fuse may blow. This may be due to a heavy load and the fuse not being securely fastened to its terminals. The screws holding the terminals of the fuse should be tight, because loose contact at these points will cause heating and an increased resistance, and, in consequence, a quicker burning of the fuse.

13. Case 12 also may happen with comparatively few passengers. The load may be caused artificially by having the brakes partially set or by dirt clogging the space between the brakeshoes and car wheels. Remove the obstruction between brakeshoes, then insert the fuse.

14. In car equipments, with motors permanently in parallel, the fuse will blow if a field or armature is short-circuited. Proceed as in case 9.

There are also other irregularities which may occur, as follows:

15. Some cables form a short circuit either under the seat or below the controller, due to dampness, dirt, damaged insulation, etc. This can readily be detected by the smell of burnt rubber. Having found the place, first open the overhead switch, then proceed to wrap rubber tape around the bare place. If this is not on hand, use some dry cotton or woolen rag torn into a narrow band or else dry string. If the wires cannot be separated far enough, place some short pieces of dry wood between them and then tie them together.

16. The car starts and after the controller reaches a certain point the fuse blows. One armature or a field is short-circuited. Cut out the faulty motor and go on with the other.

17. The car starts, stops and starts again. This may be caused by a loose contact finger at the controller or by a loose cable or wire. Remove the casing from the controller, and if blisters are seen on the drum of the controller examine the finger belonging to this particular contact, clean it and screw it home or bring it back to its normal form should it have been bent. If the controller looks all right the trouble may be found to be due to a loose cable connected to the terminals of a motor. Take a screwdriver and tighten all cables going to the field coils. armature and brush holders. Also examine the brushes. If the commutator looks dark and burnt it may be due to a brush which has worn down to such an extent that the brush springs do not press it against the commutator. In this latter case substitute a new brush, but, if none is at hand, cut out the motor and go ahead with the other.

18. The car starts with a jerk, but afterward runs smooth and normal. There is a short circuit probably

in the rheostat. Examine the rheostat terminals and remove the trouble, which may be due to the crossing of the cables or a loose cable touching another terminal. Should the trouble be internal, namely, inside of the rheostat, do not touch it at all, but run your car back to the barns and report the defects.

19. A motor field or armature coil may be burnt out. Cut out this motor, which can be detected by the smell of shellac and burnt cotton.

20. Should the speed of the motor increase beyond normal, a field magnet coil is either short-circuited or burnt out. The motor should be cut out.

21. Should there be heavy flashing and smoking in the controller, it is due to dirt, moisture, metal dust in the controller, or the too slow turning off of the controller. Open the overhead switch and blow out the dust from the ring terminals; also remove all dust at the lower ends of the controller and see that it is dry.

22. Should the lamps not light up on turning the lamp switch, see if the lamp circuit fuse is not blown. If in good order either a lamp is not screwed home into its socket or one of the lamps is burnt out. If one is burnt out none will light up, because they are in series.

There are also other irregularities which may occur which it is well for the motorman to understand, although he may not be able to remedy them.

23. One motor of a car becomes a great deal hotter than the other. This may be due to uneven distribution of work caused by difference in the magnetic circuit of the two motors, or to one set of wheels being smaller in diameter than the other, or to a ground in

the field coil or a short circuit in the field coil of the hot motor.

24. Abnormal heating of one of the motor armatures may be due to its striking the field poles when rotating.

25. Heating of the motor may also be due to a defective brake, caused by weak release springs or too short a brake chain.

26. Heating also may be due to the oil or grease used which does not melt properly, if at all. A full grease or oil cup is no sign of proper lubrication. If it is found that bearings heat, in spite of full grease cups, take a clean stick, make a hole through the grease down to the shaft, pour in soft oil and go ahead. It may be well occasionally to feel the car axle bearings, which get pretty warm when insufficiently supplied with oil.

27. A sharp rattling noise when the car is traveling at high speed is the consequence of an uneven commutator. A commutator that is flat in places, or a few bars that have become loose and project slightly, cause the brushes to be quickly forced away from the commutator by the high bars, and to be forced back onto the lower ones by the brush-holder spring as soon as a high bar has passed. This causes heavy sparking at the brushes and excessive heating of the commutator segments, besides the rapid wearing down of the brushes. The rapid succession of these changes causes the noise, and this can be remedied only in the repair shop. It should be reported.

28. A dull thumping noise, also connected with sparking at the brushes, may be due to the armature striking or rubbing against the pole pieces. If this is due to loose bearings the cap bolts should be tightened,

but if on account of worn-out boxes the car should be taken to the barn at a slow rate of speed, and reported without delay.

29. If the car starts with a jerk and the gears make considerable noise, the teeth of the pinion may be worn, fit loosely in the gear, or the key seat on the armature shaft may have been made wider by the constant wear of a loose key. This trouble should be reported as soon as possible.

30. Loud noise from the gearing is sometimes due to loose gears, the teeth of which have too much play. It is increased if the gear casing is partially opened, caused by loose bolts, or when they are removed entirely. The same trouble of improper meshing of teeth in the gears may be due to a bent armature shaft or a bent car axle. The trouble should be reported to the car inspector or other proper authority.

31. Another noise frequently heard is the thumping of a car wheel which has a flat spot. The trouble may be due to natural wear, or due to poor track, but the most frequent cause is the improper handling of the brake, which is set too suddenly and prevents the wheels from turning. If the brake is set too tightly when going down grade, it will cause the wheels to slide along the rails on four points, which, due to friction, become heated, with the result of softening that part of the wheel, which will wear rapidly into a flat place, causing a disagreeable hammering noise at every revolution of the wheel.

32. If the motors start with a jerk or do not run smoothly, the conductor should lift one of the trap doors at a time, while the car is running, to examine the commutator and brushes of each motor. Should there be seen a flash all around the commutator or

connecting two brushes, then there is an open circuit in the armature. Cut out the motor and proceed on the trip with the other motor alone.

Short Circuits and Grounds.—A short circuit on a motor in a car means that by some cause or defect a shorter circuit is found by the electric current other than is properly provided in the system, and it has the effect of weakening or disabling the part thus affected. For instance, assume that to make the magnet of a motor strong, there is placed around it 500 turns of wire; due to dampness or dirt, let there be cut out 300 or 400 turns; then a current will flow through but 100 turns; the circuit has become shorter than was intended by the designer. Such defects not only lead to irregularity in handling, but cause a strain on the dynamo in the power station. Every second that a motor runs after something is wrong is liable greatly to increase the damage. Therefore, cut out a defective motor the moment it is discovered. Short circuits can be caused by dirt and rain, by crossing of the flexible wires joined to the motors and in many other ways. A short circuit on a line means that nearly all or all the necessary resistance which a motor or other translating device should offer when in good condition has been removed by a defect, and now acts as a conductor of very little resistance connecting the two wires constituting the line. In a railway system this would mean a direct connection between trolley wire and rail, the current not properly passing through the motors.

A grounded motor, or a short circuit, means that some part of the insulation has become defective and that the current has found its way to the iron core. In most railway systems used at present the trolley wire is one of the conductors, while the rails form the sec-

ond or return conductor. A ground on a motor equipment indicates that a part of the field or the armature winding, through which the current should flow before reaching the car wheel, has been cut out of action by a defect. The car then will not operate so well, and, depending on the seriousness of the defect, will go slower or faster than when in good order. If a ground cuts out a great deal of the motor circuit it is about equivalent to a short circuit. If a guard wire, telegraph or telephone wire should fall over the trolley wire and touch the ground it would establish an earth connection, which is equivalent to a short circuit on the dynamo.

Handling Live Wires.—Should a wire be found hanging over the trolley wire, but not reaching the ground, it should be removed with the greatest of care. It does not form a ground, as it may be several feet away from the ground; however, it is charged by touching the trolley wire. In trying to remove it with the bare hands, standing on the ground, the man who intends to give his services to remove the obstruction forms himself the rest of the circuit and establishes a ground through his body. The moment he touches this apparently lifeless wire with his bare hands the current passes through his body into the ground.

A wire covered with rubber insulation can be handled, but even in this case the same precaution should be taken, as no one can tell how good the insulation may be. Frequently rubber insulation becomes brittle and hard when exposed to atmospheric changes—hot and cold weather, rain and snow—and in this state the insulation is worse than none, because persons may think the covering still to be an insulator when, in fact, it may be carbonized and itself a partial

conductor. In damp weather and with high voltages, as now commonly used, such insulation should not be relied on and should be treated as if the wire were a bare one.

The construction man on his tower wagon handles the trolley wire with bare hands, but it should be remembered that he stands on a high wooden ladder, and therefore is well insulated from the ground. Even in his lofty position he has to be on his guard, because the trolley suspension wires in some cities are connected to the iron poles without an insulator between them, only one insulator being provided, which is interposed between the trolley wire and the span. If he touches either one alone he is safe, but if he touches the trolley wire and at the same time this span wire attached to the iron pole, he establishes a connection from the trolley to the ground through his hands, arms and body and has to suffer the consequences. In most towns the trolley suspension wires are now insulated at both ends, so that they can be handled without danger.

It may be necessary to handle a live trolley wire which has broken or fallen in the street, or a telephone or other wire which has fallen across the trolley wire. Never take hold of the wire with the bare hands. If it must be handled, put several thicknesses of clothing between it and the hands, if the cloth is dry. Otherwise, use sticks and a rope to remove it.

GLOSSARY.

Ampere—The standard unit of electric current which is equivalent to the current flowing through a circuit having one ohm resistance with a pressure of one volt.

$$\text{Current} = \frac{\text{Volts}}{\text{Resistance}}$$

Armature—The part of a motor or dynamo which revolves and produces power or generates current.

Arc—An electric current flowing across the air gap or space between the points of contact.

Brushes—On railway generators and motors they are blocks of carbon held in brass holders with light springs to press them against the commutator, and through which the current passes to or from the commutator and armature, or from the stationary conductor of the circuit to the rotary conductors or vice versa.

Brush Holders—Devices to hold the brushes; they are adjustable so that the brushes can be lifted to prevent sparking.

Bucking Motor—A motor acting in opposition through some defect. The motor must be located and cut out of circuit, or turn off switches and have car conveyed to depot.

Catenary Trolley—A trolley wire which is supported by hangers from a steel cable running just above the copper wire itself.

Circuit-Breaker—An automatic switch arranged to open whenever the current becomes greater than a certain predetermined amount. It consists of a few turns of wire around an iron core, which becomes a magnet of greater and greater power as the current increases until it throws open the switch or releases a catch which allows a spring to open the switch.

Closed Circuit—A circuit is closed when its conducting parts are so connected as to allow the current to flow.

Commutator—A set of copper segments separated by thin strips of mica insulation in the form of a drum; through the segments covered by the positive brushes the positive current passes to the armature in a motor and from it in a dynamo.

Compound Winding—The field magnets of a railway dynamo always have two windings, through one of which, the "series," the main current passes, and through the other, the "shunt," a branch of the main current passes.

Conductors—The part of the dynamo, motor or line, or circuit through which the current flows.

Counter-Electro-Motive Force—The pressure generated in the armature of the motor or dynamo.

Cut Off from the Line—Open Circuit. Car disabled by an open circuit.

Diverter—A rheostat or resistance placed in circuit with a motor to reduce the current.

Electro-Magnet—An iron or steel core around which a spool of wire is placed carrying current.

Electro-Motive Force—The voltage or volts' pressure in a circuit; e. g., the trolley circuit has an electromotive force of 500 volts. The abbreviation is e. m. f.

Field—The part of a motor or dynamo which contains the magnets.

Fuse—A strip of metal, generally some alloy of lead, which easily melts when too great a current is flowing in the circuit. It is mounted usually on a piece of porcelain called a fuse block.

Generator—Has the same meaning as dynamo, but is commonly used to denote the large machines in the station.

Grounded Circuit—A circuit in which the ground forms part of the conducting path.

Horsepower—The standard rate of work being 33,000 foot-pounds per minute. If a machine can lift 1,000 pounds 33 feet in one minute its capacity is one horsepower. The abbreviation is hp. Electrical equivalent, 1 hp.=746 watts.

Insulation—A non-conductor, as air, rubber, mica, varnish, etc., through which electricity does not readily pass.

Interlocking Device—A part of the controller which prohibits the motorman from reversing while the current is on.

Lightning Arresters—They are devices which offer a by-pass to lightning to prevent damage to machines when the line is carrying a discharge of lightning by conducting it to the earth.

Magnetic Blow-Out—When switches are opened or current shut off in controllers, an arc is formed which is current passing through the air from one conductor to the other. A magnet is placed near the

point where the arc is formed and draws it aside and blows it out.

Ohm—The standard of electrical resistance through which one ampere of current will flow with a pressure of one volt. Ohms = Volts ÷ Current.

Open Circuit—A circuit is open when its conducting parts are disconnected in such a manner as to prevent the current from flowing.

Parallel or Multiple Connection—A circuit in which the current divides and part passes through each motor, dynamo or other electrical device.

Poles or Pole Pieces—The core ends which project on the fields and conform to the shape of the armature, and generally carry the field windings.

Resistance—An obstruction to the flow of current. All substances have some resistance, but resistance boxes or rheostats have iron wire or sometimes carbon strips for the circuit. Resistance produces heat in the circuit, and by this means the current in passing through an electric car heater makes the wires very hot.

Reversing Cylinder—The part of the controller which controls the direction of motion of the motors.

Rotary Converter—A type of electrical machine for changing direct to alternating current, or vice versa.

Safety Stop—An attachment which prevents the controller cylinder from being turned past a certain running position when a motor is cut out.

Series Connection—When the current passes through one motor, dynamo or electrical device and thereafter into one or more devices.

Short Circuit—A short cut made by the current to a path outside of the regular circuit.

Sparking—The flashing of the current which occurs at the commutator when there is poor contact, the brushes are in bad order, the commutator is dirty, or the dynamo or motor is carrying too heavy a load.

Transformer—A combination of coils of wire about an iron core by means of which alternating current can be changed in pressure.

Volt—The standard of electrical pressure, or the pressure to force one ampere of current through one ohm resistance. Volts = Amperes × Ohms.

Watt—The rate of performance of work measured electrically; the capacity of a dynamo or motor is measured in watts and is the product of volts by amperes. A kilowatt is 1,000 watts and is equal to 1.34 hp.

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